MR No. A5G23

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

WARTIME REPORT

ORIGINALLY ISSUED

July 1945 as
Memorandum Report A5G23

WIND-TUNNEL INVESTIGATION OF THE EFFECTS OF SPOILERS ON THE CHARACTERISTICS OF A LOW-DRAG AIRFOIL EQUIPPED WITH A 0.25-CHORD SLOTTED FLAP

By Ralph W. Holtzclaw

Ames Aeronautical Laboratory
Moffett Field, California

NACA

WASHINGTON

MR No. A5G23

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

MEMORANDUM REPORT

for the

Bureau of Aeronautics, Navy Department

WIND-TUNNEL INVESTIGATION OF THE EFFECTS OF SPOILERS ON THE CHARACTERISTICS OF A LOW-DRAG AIRFOIL EQUIPPED WITH A 0.25-CHORD SLOTTED FLAP

By Ralph W. Holtzclaw

SUMMARY

An investigation was made to determine the effects of circular-arc spoilers on the section characteristics of an NACA 66,2-216 (a = 0.6) airfoil equipped with a 0.25-chord slotted flap. Spoilers were tested on the upper surface of the airfoil at 0.725 chord, on the lower surface at 0.6666 chord, and on both surfaces simultaneously.

The upper-surface spoiler was unsatisfactory as a lateral-control device because of its tendency to produce rolling moments in the wrong direction for small spoiler deflections with the flap deflected and the nonlinear variation of effectiveness with spoiler deflection. Sealing the flap slot eliminated the reversal but caused a considerable loss in flap effectiveness and spoiler effectiveness with the flaps deflected. The lower-surface spoiler was also unsatisfactory because of the unfavorable variation of spoiler effectiveness with flap deflection. A combination of small deflections of the lower-surface spoiler with small deflections of the upper-surface spoiler, though rather complicated, gave quite satisfactory results. Although there was still a nonlinear variation of spoiler effectiveness with deflection, it was shown to be improved considerably by the use of the proper variation of spoiler deflection with control travel.

Calculations of the characteristics of three hypothetical airplanes equipped with spoiler control systems indicated that

satisfactory lateral control could be obtained.

INTRODUCTION

With ailerons of the conventional type covering a considerable portion of the wing trailing edge, it is generally possible to use only partial-span flaps. The need for the greater effectiveness afforded by full-span flaps is increasing as airplane wing loadings increase. As a result, the NACA is conducting research to develop lateral-control devices that will permit the use of full-span flaps. The most promising of these devices are drooped-aileron and spoiler-type lateral controls.

The results of references 1, 2, and 3 have indicated that circular-arc spoilers[1] may provide satisfactory lateral control. The present investigation was conducted to determine the characteristics of a spoiler control on a low-drag airfoil. The effects of spoilers, on either the upper or lower surface or in combination, on the characteristics of a low-drag airfoil equipped with a 0.25-chord slotted flap were determined. The results were applied to the estimation of the lateral-control characteristics of three hypothetical airplanes equipped with spoiler controls.

The tests were conducted in the Ames 7- by 10-foot wind tunnel No. 1.

COEFFICIENTS AND CORRECTIONS

The coefficients used throughout this report are as follows:

c_l section lift coefficient

Δc_l increment of section lift coefficient

c_{d_o} section profile drag coefficient

Δc_{d_o} increment of section profile drag coefficient

c_m section pitching-moment coefficient about quarter chord of section with flap in neutral position

---

[1] Also referred to as retractable ailerons when used on the rearward portion of an airfoil.

C_l rolling-moment coefficient (L/qSb)

C_{l_S} the rolling-moment coefficient due to spoiler deflection

C_{l_p} the rolling-moment coefficient due to rolling $\left[\partial C_l/\partial\left(\frac{pb}{2V}\right)\right]$

L_p lateral stability coefficient derivative $\left(\frac{1}{4}\ b^2\ C_{l_p}\ \frac{\rho Vs}{I_X}\right)$

where

L rolling moment, foot-pounds

q dynamic pressure $(\frac{1}{2}\rho V^2)$, pounds per square foot

ρ the mass density of air, slugs per cubic foot

b wing span, feet

I_X moment of inertia about the X-axis, slug-feet square

S the wing area, square feet

V velocity, feet per second

In addition, the following symbols are employed:

α_o angle of attack for infinite aspect ratio, degrees

δ_{S_U} spoiler deflection from upper surface, degrees

δ_{S_L} spoiler deflection from lower surface, degrees

δ_f flap deflection, degrees

$pb/2V$ helix angle generated by wing tip in roll, radians

Φ angle of bank, degrees

β angle of sideslip, positive when right wing is forward, degrees

ψ angle of yaw, positive when left wing is forward, degrees

t time, seconds

θ fraction of control travel

The lift, profile-drag, and pitching-moment coefficients have been corrected for tunnel-wall effects. All the results have been corrected for the end-plate effects described in reference 4.

MODEL AND APPARATUS

The airfoil was constructed of laminated mahogany to the NACA 66,2-216 (a = 0.6) profile of 4-foot chord. This was the same model as that used for the tests of reference 4. It was equipped with a 0.25-chord slotted flap constructed to the profile of the normal section; the slot entry was designed to reduce the gap with the flap retracted to the practical minimum (flap and slot B of reference 4). The airfoil ordinates are given in table I, and the flap ordinates are given in table II. The details of the slot are shown in figure 1. Tests were also made with the slot sealed as shown in figure 2.

The spoilers used for this investigation consisted of perforated metal plates shaped to a radius of 0.12 chord and were rigidly attached to the airfoil. Details of the spoiler construction and installation are shown in figures 1 and 3. As it is usually assumed that circular-arc spoilers have negligible hinge moments, no attempt was made to measure their hinge moments on the test installation. Although it was realized that the flanges used on the larger spoilers (fig. 3) would contribute hinge moment, they were used only to give increased rigidity and were assumed not to exist on an actual installation. The spoilers were perforated to minimize buffeting. The spoiler on the upper surface of the airfoil was 0.725 of the chord from the airfoil leading edge, while that on the lower surface was 0.6666 of the chord from the leading edge. These locations were dictated by the model structure and do not necessarily represent an optimum aerodynamic arrangement. However, an attempt was made to locate the spoilers as far aft as possible in order to reduce the time lag (reference 5).

The model, equipped with the 45° spoiler on the upper surface, is shown mounted vertically in the Ames 7- by 10-foot wind tunnel No. 1 in figure 4.

TESTS

The tests were conducted at a dynamic pressure of 50 pounds per square foot, corresponding to a Reynolds number of approximately 5,100,000 and a Mach number of approximately 0.19. Lift, drag, and pitching-moment measurements were made throughout the useful angle-of-attack range for constant spoiler and flap deflections. The flap path, shown in figure 5, corresponded to the path selected (reference 4) for the flap slot tested.

The upper- and lower-surface spoilers were each tested with flap deflections of 0°, 10°, 20°, 30°, 40°, and 45° with spoiler deflections of 0°, 2.5°, 5°, 10°, 15°, 30°, 45°, and 60°. The effects of sealing the flap slot were measured for flap deflections of 0°, 20°, and 40° for the upper-surface-spoiler deflections (excepting 60°) previously listed. The interaction of simultaneous deflections of upper- and lower-surface spoilers was also measured for small deflections of the lower-surface spoiler (limited to 10°), flap deflections of 0°, 20°, and 40°, and for a limited range of upper-surface-spoiler deflections.

RESULTS AND DISCUSSION

The characteristics of the airfoil for the range of flap deflections investigated are presented in figure 6. These data have been presented previously in figure 13 of reference 4.

The results of the tests with deflected spoilers are presented in the form of section pitching-moment coefficients and increments of section lift and profile drag coefficients due to spoiler deflection plotted against the spoiler deflection for a constant flap deflection and angle of attack. The data are presented for corrected angles of attack of -4°, 0°, 4°, 8°, and 12°. It should be noted that the actual experimental data were obtained for a constant spoiler deflection as a function of the uncorrected angle of attack. After the corrections were applied, the data were plotted for the corrected angle of attack before the final cross-plotting against spoiler deflection.

Upper-Surface Spoiler

The results of the tests with the spoiler on the upper surface are presented in figure 7 for flap deflections from 0° to 45°, inclusive. The variation of the increment of section lift coefficient c_{l_S} with spoiler deflection showed an abrupt decrease of $\partial\Delta c_l/\partial\delta_{S_U}$ at a spoiler deflection of about 7.5° (fig. 7). For flap deflections of 30° or greater, there was also a reversal in sign of the lift increment for small spoiler deflections, the magnitude of the reversal increasing with flap deflection. Either of these effects would be objectionable in a lateral-control device. The maximum available lift-coefficient increments occurred with 30° and 40° flap deflections.

The variation of the pitching-moment coefficient and the increment of profile drag coefficient, due to spoiler deflection, showed irregularities corresponding to those shown by the variation of the lift-coefficient increments (fig. 7).

Upper-Surface Spoiler with Sealed Flap Slot

In an effort to eliminate the reversal in the lift-coefficient increments and the abrupt change in $\partial\Delta c_l/\partial\delta_{S_U}$, the flap slot was sealed as shown in figure 2. Results are presented in figure 8 for this condition for flap deflections of 0°, 20°, and 40° and for spoiler deflections from 0° to 45°, inclusive. A comparison of figures 7 and 8 shows that the seal almost entirely eliminated the reversal (a slight reversal still existed for an angle of attack of 0° for a flap deflection of 20° and an angle of attack of 12° for a flap deflection of 40°), but the seal did not alleviate the abrupt change in $\partial\Delta c_l/\partial\delta_{S_U}$. As illustrated by figure 9 (spoiler deflection = 45°), the seal had practically no effect on the available section lift-coefficient increment due to spoiler deflection with the flap retracted. However, with the flap deflected, the seal seriously decreased the incremental lift, the reduction increasing with angle of attack.

The characteristics of the airfoil with the flap slot sealed (spoiler undeflected) are shown in figure 10 for flap deflections of 0°, 20°, and 40°. A comparison of this figure with figure 6 shows that the seal reduced the maximum section lift coefficient with 40° flap deflection from 2.82 to 2.21. The increment of section lift coefficient due to flap deflection is shown in figure 11 for the slot sealed and in figure 12 for the slot unsealed. As shown by these figures, the amount that the seal decreased the flap effectiveness increased with angle of attack. It should be noted that the poor characteristics with the slot sealed may have been partly due to the method of sealing the slot. (See fig. 2.) No provision had been made in the model for a conventional internal seal, so the type used was resorted to in an effort to obtain an approximation of the effect of sealing the slot. Since it was difficult to maintain an adequate seal with only one surface sealed at the dynamic pressure required, both upper and lower surfaces were sealed.

Lower-Surface Spoiler

The results of the tests with the spoiler on the lower surface are presented in figure 13 for flap deflections from 0° to 45°,

inclusive. These data indicate that the lower-surface spoiler alone would be unsatisfactory as a lateral-control device due to the unfavorable variation of c_{l_S} with flap deflection. For small flap deflections the action of the spoiler is similar to that of a flap; that is, it produces positive lift increments. However, as the flap deflection is increased the increments are reduced until, at a flap deflection of 30°, the increments are all negative. There was also a reversal in the sign of the lift increments for flap deflections of 0° and 10°. As the flap deflection was increased the effect was reduced and it disappeared with a flap deflection of 30°.

Combined Upper- and Lower-Surface Spoilers

Observations of the independent action of the upper- and lower-surface spoilers suggested the combination of the upper-surface spoiler with small deflections of the lower-surface spoiler. A limited number of tests of various combinations were made. The results are presented in figures 14, 15, and 16 for lower-surface spoiler deflections of 2.5°, 5°, and 10°, respectively. From these results, an upper- and lower-surface spoiler combination has been selected. Data for this combination are presented in figure 17. For this arrangement the upper- and lower-surface spoilers deflect simultaneously with $\delta_{S_U} = 2\delta_{S_L}$ until a deflection of 5° of the upper-surface spoiler and a deflection of 2.5° of the lower-surface spoiler have been reached. At this point the lower-surface spoiler starts to retract at half the rate the upper-surface spoiler deflects until, at an upper-surface-spoiler deflection of 10°, the lower-surface spoiler is fully retracted. As the deflection of the upper-surface spoiler is increased, the lower-surface spoiler remains retracted.

As shown by figure 17, the selected combined spoiler arrangement did eliminate the reversal although it did not eliminate the abrupt change in $\partial\Delta c_l/\partial\delta_{S_U}$ (particularly with the flap deflected). In an actual installation this defect might be alleviated to some extent by the use of a properly chosen relationship between the control deflection and the spoiler deflection as illustrated later in this report.

As might be expected, it was found that the effects of an upper-surface spoiler and a lower-surface spoiler were not directly additive when used in combination. This fact is illustrated by figure 18 which shows that the sum of the individual effects does not closely approximate the measured result.

Estimation of the Characteristics of Airplanes Equipped with Spoiler Installations

In order to determine if the spoilers tested would meet the requirements for a satisfactory lateral-control device, an estimate was made of the lateral-control characteristics of three hypothetical airplanes assuming full-span-flap and spoiler installations. The estimated characteristics were then compared with the characteristics required for a satisfactory control. The airplanes chosen for analysis are types which might profitably use a full-span-flap installation. Their assumed general characteristics are given in table III. Airplane A is a large, four-engine, long-range bomber; airplane B is a large-two-engine, patrol bomber; and airplane C is a carrier-based, single-engine scout bomber.

Computations have been made of rudder-locked rolls for each of the three airplanes for the high-speed flight condition and for the landing approach with the flaps extended. The section lift and profile-drag coefficients were first converted to rolling- and yawing-moment coefficients by the method of references 6, 7 and 8. These values were then used for the calculation of $pb/2V$ and the angles of bank, sideslip, and yaw as a function of time by the method of references 9 and 10. (The results of these calculations are later referred to as the time histories of the roll.)

Assumptions.- In estimating the characteristics of the airplanes with spoiler controls, the following assumptions have been made:

1. The combined spoiler arrangement of figure 17 has been assumed for all three airplanes.

2. The spoiler span has been assumed to be the same as the span of the ailerons of the particular airplane.

3. Slotted flaps of 0.25 wing chord have been assumed to replace the ailerons of the particular airplane.

4. It has been assumed that the spoilers did not cause a change in the stability derivatives of the wings. It is realized that this assumption is not correct (reference 11); however, the results are believed to be indicative of the characteristics with the spoiler installations.

5. Rigid wings have been assumed throughout the calculations.

6. No allowance has been made in the calculations for Mach number effects.

7. The values of pb/2V computed for the landing approach have been assumed applicable to the landing condition.

8. The variation of spoiler deflection with control travel shown in figure 19 has been assumed for all three airplanes. This assumption was made in an effort to make the maximum rolling velocity approximately proportional to control deflection.

9. The hinge moments of the circular-arc spoilers have been assumed to be negligible, and it has been further assumed that the necessary control forces would be provided by artificial means.

10. For the landing approach, the outboard flaps have been assumed to be deflected sufficiently to give an increment of section lift coefficient of 0.8. (This amounts to a deflection of about 15° for all three airplanes.) The estimated reduction in landing speeds due to deflection of the outboard flaps and the landing approach speeds of the three airplanes used in the calculations are shown in the following table:

Airplane	Reduction in landing speed due to outboard flaps, mph	Landing approach speed, mph
A	7.4	98
B	5.4	105
C	3.8	86

Greater reductions could be had with increased flap deflections. However, experiments (reference 12) have indicated a deterioration in stalling characteristics and lateral stability near and at the stall of airplanes with full-span flaps when the wing was too heavily loaded at the tip. For that reason, a small deflection was chosen to be conservative.

Calculated characteristics.— Roll time histories (assuming instantaneous control deflection) are presented in figures 20, 21, and 22 for airplanes A, B, and C, respectively. For comparison with the peak value determined for the rudder-locked condition, pb/2V was also computed for maximum control travel (on the basis that zero

sideslip was maintained) using the following expression:

$$\frac{pb}{2V} = \frac{C_{l_S}}{C_{l_p}} \left(e^{L_p t} - 1\right) \quad \text{(See reference 10.)}$$

When the time is large this equation reduces to

$$\frac{pb}{2V} = - \frac{C_{l_S}}{C_{l_p}}$$

The variation of maximum $pb/2V$ with control travel for each of the three airplanes is shown in figure 23.

Control effectiveness.- For a satisfactory lateral-control device, the variation of rolling acceleration with time immediately following an abrupt control deflection should always be in the correct direction and without perceptible lag. Inspection of figures 20, 21, and 22 indicates that the rolling acceleration is in the correct direction for all three airplanes as evidenced by the positive gradient of the variation of $pb/2V$ with time.

In the past, time lag has been one of the main objections to spoiler-type controls. It has been shown (reference 5) that, for conventional airfoils, spoilers located aft of 0.80 chord have negligible lag. Flight tests of a 0.17-chord-radius spoiler located at 0.765 of the chord showed a lag of 0.1 second. (See reference 1.) The pilots did not consider this amount of lag objectionable. However, it has been concluded (reference 13) that lag much in excess of 0.1 second would be objectionable; a lag of 0.25 second would not be acceptable. (See reference 14.)

The data of references 5 and 15 on the lag of spoilers at various chordwise positions have been plotted on a nondimensional basis by dividing the lag by c/V where c is the mean chord at the spoiler and V is the velocity of the airplane. The mean curve so determined is shown in figure 24. Using this curve as a basis, the lag (in seconds) for the three exemplary airplanes is estimated to be as follows:

Airplane	High Speed	Landing Approach
A	0.035	0.104
B	.040	.087
C	.029	.089

Assuming a criteria of a maximum lag of 0.1 second, the lag would probably not be objectionable for any of the airplanes.

At any speed, the maximum rolling velocity obtained by abrupt deflection of the lateral control with the rudder locked in its trim position should vary smoothly with and be approximately proportional to the control deflection. As shown by figure 23, the rate of roll is not exactly proportional to control movement – particularly for the landing approach. This condition, however, is probably not serious enough to render the controls unsatisfactory.

The lateral control should be of sufficient power to produce a wing-tip helix angle $pb/2V$ equal to or greater than 0.09 for airplanes such as fighters, dive bombers, and torpedo bombers, and 0.07 for horizontal bombers, cargo, transport and primary training airplanes in the high-speed flight condition with the rudder locked in its trim position. The required values are somewhat lower for speeds in excess of 300 miles per hour. The lateral control should also be capable of producing a $pb/2V$ of 0.07 for all airplanes in the landing condition with the rudder locked in its trim position. As shown by figure 23, airplanes A and B attain a $pb/2V$ well in excess of 0.07 thus satisfying this requirement. The maximum $pb/2V$ for airplane C in the high-speed condition is only 0.084 compared to the value of 0.09 required. It should be noted that the spoiler span assumed for this airplane is only 29 percent wing span. Airplane C could meet this requirement with a slight increase in the spoiler span.

As shown by figures 20 to 22, the maximum values of $pb/2V$ computed for the high-speed flight condition rudder locked are larger than those computed for zero sideslip for all three airplanes. The rudder-locked values are higher because the slightly favorable yaw developed by the spoilers aids the roll. For the approach condition, the values computed for zero sideslip are greater than those with the rudder locked for airplanes A and C. For this condition (rudder locked), the favorable yawing moment due to the profile drag of the spoilers is more than offset by the yawing moment due to the incremental induced drag which opposes the

roll. For airplane B the values of $pb/2V$ rudder locked are about the same as the values for zero sideslip. It should be noted that, for airplane B in the approach condition, a relatively high static directional stability and low static lateral stability combine to make the airplane dynamically unstable. This is the source of the high values of $pb/2V$ shown in figures 21(b) and 23.

For all airplanes the product of the rolling velocity and the wing span should be at least 10 feet per second for the landing condition when the airplane is rolled with abrupt full aileron deflection with the rudder locked in its trim position. The product of the rolling velocity and the wing span is shown in the following table for each of the three airplanes.

Airplane	Product of rolling velocity and wing span
A	25.2
B	48.9
C	51.0

As shown by the above table all three airplanes satisfy this requirement.

The angles of sideslip for the airplanes in the high-speed condition, though quite small, are generally negative. (For normal aileron control, the sideslip angles are usually positive.) For the approach condition, the sideslip angles are positive for all three airplanes and in no case become excessive.

The angles of yaw are generally small although positive for high speed and slightly negative for approach speeds. This characteristic, coupled with the sideslip characteristics, would probably require some familiarization flights for pilots to become accustomed to the spoiler controls. Pilots accustomed to airplanes with conventional controls would probably tend to overcontrol, particularly in landing.

Control forces.— As previously mentioned, it has been assumed that control forces would be provided artificially so that all control-force requirements are assumed to be satisfied.

Theoretically, circular-arc spoilers have no hinge moments. Attempts have been made to develop such spoilers that would provide their own hinge moments (for example, reference 2) by providing them with vented flat tops. The hinge-moment characteristics were unsatisfactory, however, particularly with the flaps down. It appears that further development is required before these spoilers can be considered satisfactory.

It might be noted that difficulties in flight with the hinge-moment characteristics of plain, circular-arc spoilers have been encountered due to the large frictional and inertia forces involved in the particular operational systems and the fact that the arcs of the spoilers were not truly circular.

One solution to the problem of obtaining satisfactory control-force characteristics, which has been used in a few cases, is the use of very-short-span (10- to 15-percent span), conventional, unbalanced ailerons at the wing tip (feeler ailerons). Flaps cover the remainder of the span; and the spoilers, which provide the control, are located ahead of the flaps. This system necessarily gives less available total lift than can be had with full-span flaps. However, the reduction may not be serious. For example, decreasing the flap span on a wing of 2:1 taper from full span to 85-percent span reduces the lift increment due to flap deflection less than 10 percent. (See reference 8.) The possible deterioration of lateral stability near the stall of wings with the tips too heavily loaded is an objection to the use of full-span flaps. The use of short-span (10 to 15 percent) feeler ailerons would tend to minimize this difficulty. Feeler ailerons also tend to mask any lag present in the control system.

Flight tests of a high-speed airplane equipped with 15-percent-span feeler ailerons and 31-percent-span circular-arc spoilers have given quite satisfactory results. Some lag was noticed with the flaps down although not of sufficient magnitude to be considered objectionable by the pilots. Also, the inertia forces of the particular system were considered somewhat objectionable. However, the pilots, in general, were quite satisfied with the control; the effectiveness was sufficient and the force variations were considered satisfactory. No difficulties were encountered in performing smooth, accurate maneuvers after the pilots had flown the airplane a very short time to become familiar with the control.

From the foregoing discussion it appears that spoilers can be used successfully as a lateral-control device. Although somewhat complicated, spoiler controls permit the use of full-span or nearly

full-span flaps. One of the main disadvantages to their use is that the proper force characteristics must be provided artificially or by the use of feeler ailerons.

Spoilers on thin wings.- All the data presented in this report were obtained from tests of a 16-percent-thick airfoil at low Mach numbers. Preliminary design considerations of spoilers on thin wings for use on very high-speed airplanes indicate that a satisfactory installation will be considerably complicated because of the extreme thinness of the aft portion of the airfoil.

CONCLUSIONS

The results of tests to evaluate the effects of spoilers on the characteristics of a low-drag airfoil equipped with a 0.25-chord slotted flap indicated the following:

1. Spoilers can be applied to airplanes as a satisfactory lateral-control device, as illustrated by the calculations of the lateral-control characteristics of three hypothetical airplanes.

2. A system of spoilers combining very small deflections of lower-surface spoilers with the small deflections of upper-surface spoilers, though quite complicated, eliminated the tendency of the upper-surface spoilers to produce roll in the wrong direction at small deflections. There was still a nonlinear variation of spoiler effectiveness with spoiler deflection, but this was improved considerably by the use of the proper variation of spoiler deflection with control travel.

3. Sealing the flap slot also eliminated the tendency to produce roll in the wrong direction but caused a considerable loss in flap effectiveness and spoiler effectiveness with the flaps deflected.

Ames Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Moffett Field, Calif.

REFERENCES

1. Soulé, H. A., and McAvoy, W. H.: Flight Investigation of Lateral Control Devices for Use with Full-Span Flaps. NACA Rep. No. 517, 1935.

2. Wetmore, J. W.: Flight Tests of Retractable Ailerons on a Highly Tapered Wing. NACA TN No. 714, 1939.

3. Wenzinger, Carl J., and Bamber, Millard J.: Wind-Tunnel Tests of Three Lateral-Control Devices in Combination With a Full-Span Slotted Flap on an NACA 23012 Airfoil. NACA TN No. 659, 1938.

4. Holtzclaw, Ralph W., and Weisman, Yale: Wind-Tunnel Investigation of the Effects of Slot Shape and Flap Location on the Characteristics of a Low-Drag Airfoil Equipped with a 0.25-Chord Slotted Flap. NACA CMR No. A4L28, 1944.

5. Weick, Fred E., and Shortal, Joseph A.: Development of the NACA Slot-Lip Aileron. NACA TN No. 547, 1935.

6. Pearson, Henry A., and Jones, Robert T.: Theoretical Stability and Control Characteristics of Wings with Various Amounts of Taper and Twist. NACA Rep. No. 635, 1938.

7. Pearson, H. A.: Theoretical Span Loading and Moments of Tapered Wings Produced by Aileron Deflection. NACA TN No. 589, 1937.

8. Pearson, H. A.: Span Load Distribution for Tapered Wings with Partial-Span Flaps. NACA Rep. No. 585, 1937.

9. Donlan, C. J., and Recant, I. G.: Methods of Analyzing Wind-Tunnel Data for Dynamic Flight Conditions. NACA TN No. 828, 1941.

10. Jones, Robert T.: A Simplified Application of the Method of Operators to the Calculation of Disturbed Motions of an Airplane. NACA Rep. No. 560, 1936.

11. Weick, Fred E., and Jones, Robert T.: The Effect of Lateral Controls in Producing Motion of an Airplane as Computed from Wind-Tunnel Data. NACA Rep. No. 570, 1936.

12. Irving, H. B., Warsap, J. H., Batson, A. S., and Gummer, H. J.: Some Aerodynamic Characteristics of Tapered Wings Fitted with Flaps of Various Spans. R.& M. No. 1796, British A.R.C., 1937.

13. Shortal, Joseph A.: Wind-Tunnel and Flight Tests of Slot-Lip Ailerons. NACA Rep. No. 602, 1937.

14. Weick, Fred E.; Soulé, Hartley A.; and Gough, Melvin N.: A Flight Investigation of the Lateral Control Characteristics of Short Wide Ailerons and Various Spoilers with Different Amounts of Wing Dihedral. NACA Rep. No. 494, 1934.

15. Shortal, J. A.: Effect of Retractable-Spoiler Location on Rolling- and Yawing-Moment Coefficients. NACA TN No. 499, 1934.

TABLE I.– NACA 66,2–216 (a = 0.6) AIRFOIL
[Stations and ordinates are given in percent of the airfoil chord]

Upper surface		Lower surface	
Station	Ordinate	Station	Ordinate
0	0	0	0
.371	1.242	.629	–1.112
.607	1.501	.893	–1.319
1.091	1.886	1.409	–1.608
2.317	2.615	2.683	–2.127
4.794	3.701	5.206	–2.869
7.284	4.563	7.716	–3.441
9.781	5.308	10.219	–3.934
14.788	6.500	15.212	–4.702
19.806	7.428	20.194	–5.290
24.832	8.155	25.168	–5.741
29.862	8.708	30.138	–6.080
34.897	9.098	35.103	–6.312
39.936	9.356	40.064	–6.462
44.978	9.471	45.022	–6.523
50.023	9.431	49.977	–6.483
55.073	9.224	54.927	–6.336
60.141	8.800	59.859	–6.048
65.191	8.084	64.809	–5.574
70.198	7.068	69.802	–4.866
75.181	5.889	74.819	–4.037
80.148	4.585	79.852	–3.107
85.106	3.265	84.894	–2.177
90.061	1.937	89.939	–1.235
95.021	0.762	94.979	–.432
100	0	100	0
Leading-edge radius: 1.575 Trailing-edge radius: 0.0625			

TABLE II.– ORDINATES FOR THE 0.25–CHORD SLOTTED FLAP ON THE NACA 66,2–216 (a = 0.6) AIRFOIL

[Stations and ordinates in percent of airfoil chord]

Station	Upper surface	Lower surface
75.000	–1.875	– – –
75.521	.042	–3.062
76.042	.895	–3.437
77.083	1.937	–3.604
78.125	2.646	–3.417
79.167	3.125	–3.229
80.208	3.458	–3.042
81.250	3.646	–2.854
82.292	3.687	–2.646
83.333	3.625	–2.437
84.375	3.437	–2.250
85.417	3.208	–2.062
87.500	2.646	–1.667
89.583	2.083	–1.292
91.667	1.542	–.917
93.750	1.062	–.583
95.833	.604	–.333
97.917	.271	–.167
100.000	0	0
T.E. radius: 0.0625		

TABLE III.– CHARACTERISTICS OF HYPOTHETICAL AIRPLANES EQUIPPED WITH SPOILER INSTALLATIONS

Characteristics	Airplane A (heavy bomber, four-engine)	Airplane B (large two-engine patrol bomber)	Airplane C (carrier-based scout bomber)
Wing loading (lb/sq ft)	61.3	45	39.2
Aspect ratio	11.65	10	5.4
Taper ratio	0.436	0.5	0.5
Wing area (sq ft)	1714	1000	375
Wing span (ft)	141	100	45
Inboard flap span (percent span)	60	60	67
Outboard flap span (percent span)	37	36	29
K_X Radius of gyration about X-axis, feet	21.45	14.5	5.54
K_Z Radius of gyration about Z-axis, feet	26.4	18	9.13

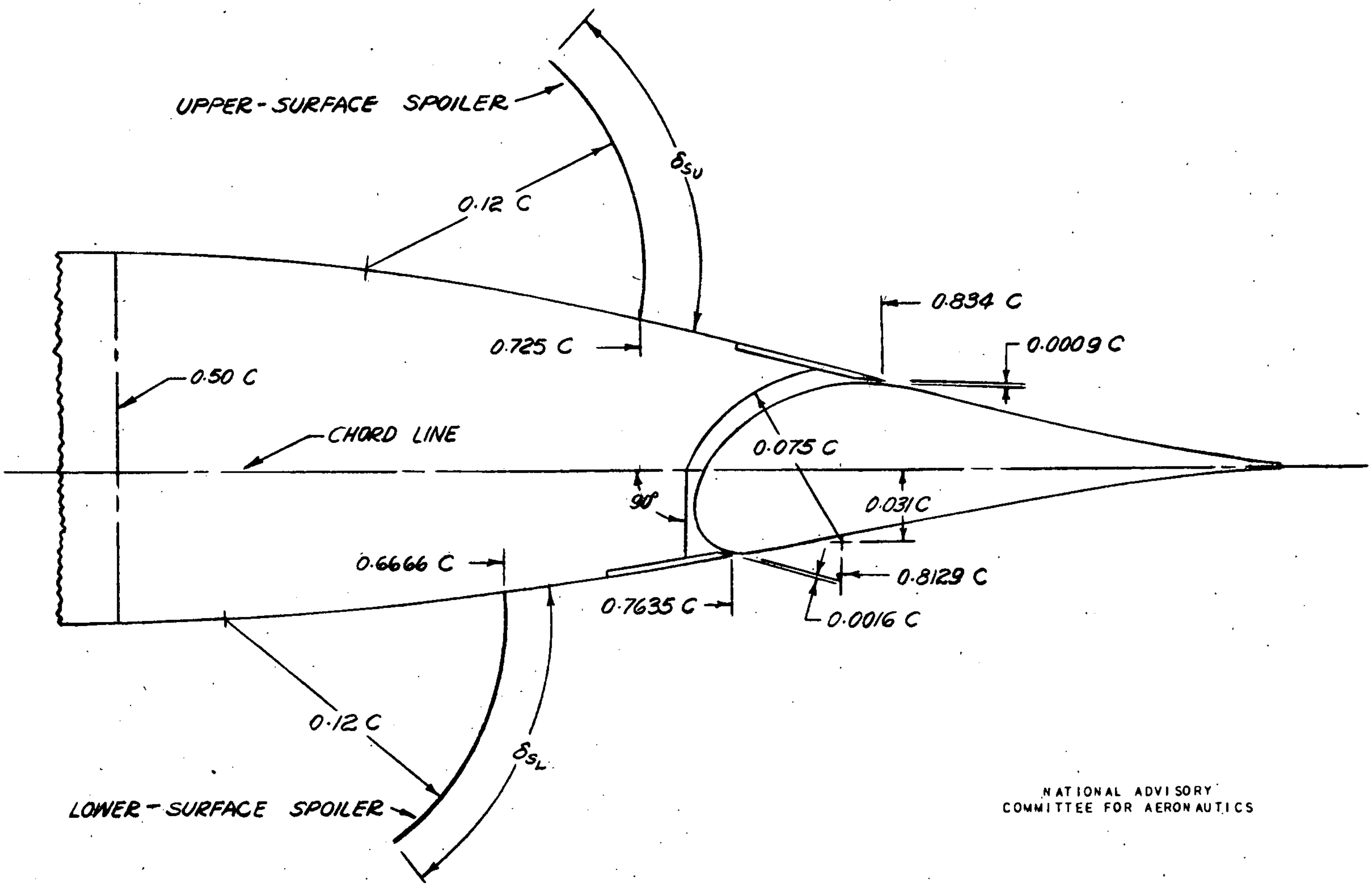


FIGURE 1.- DETAILS OF THE SPOILERS AND THE FLAP SLOT TESTED ON THE NACA 66,2-216 (a=0.6) AIRFOIL EQUIPPED WITH A 0.25-CHORD SLOTTED FLAP

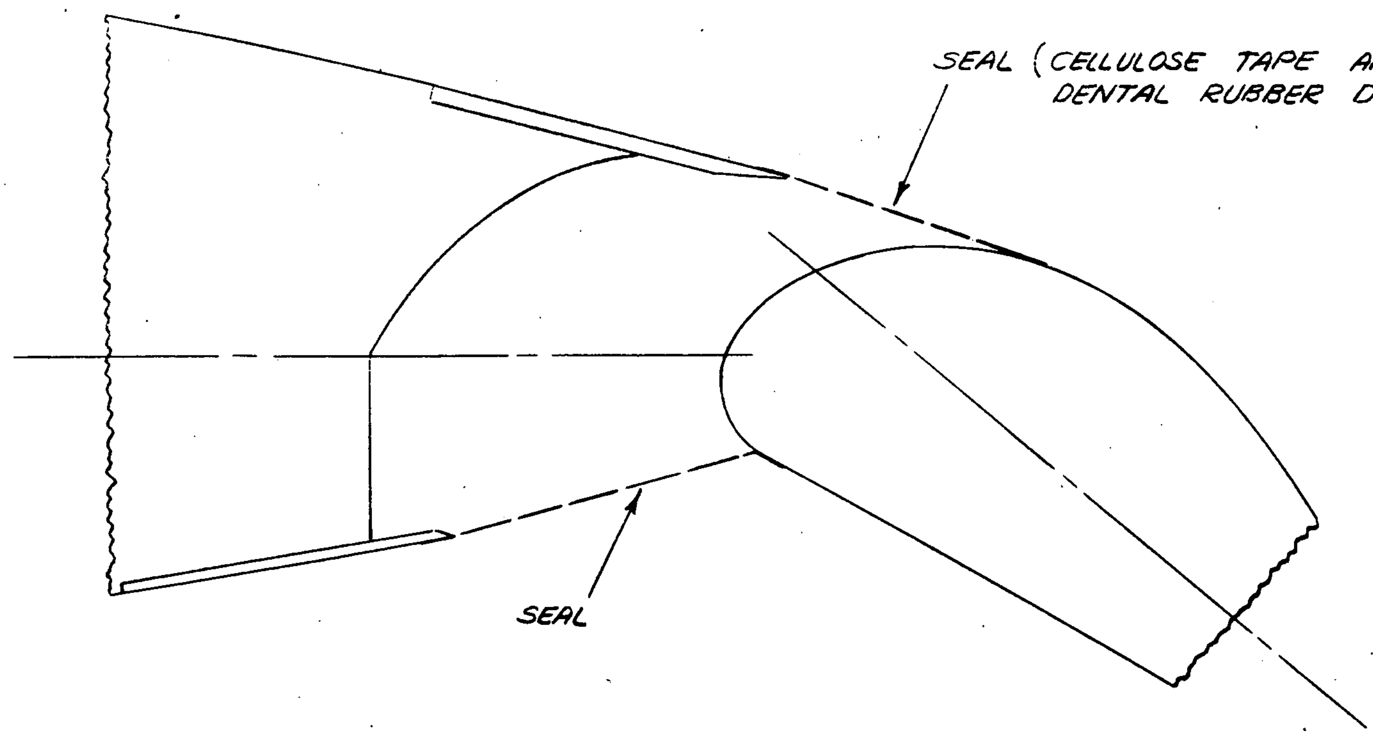
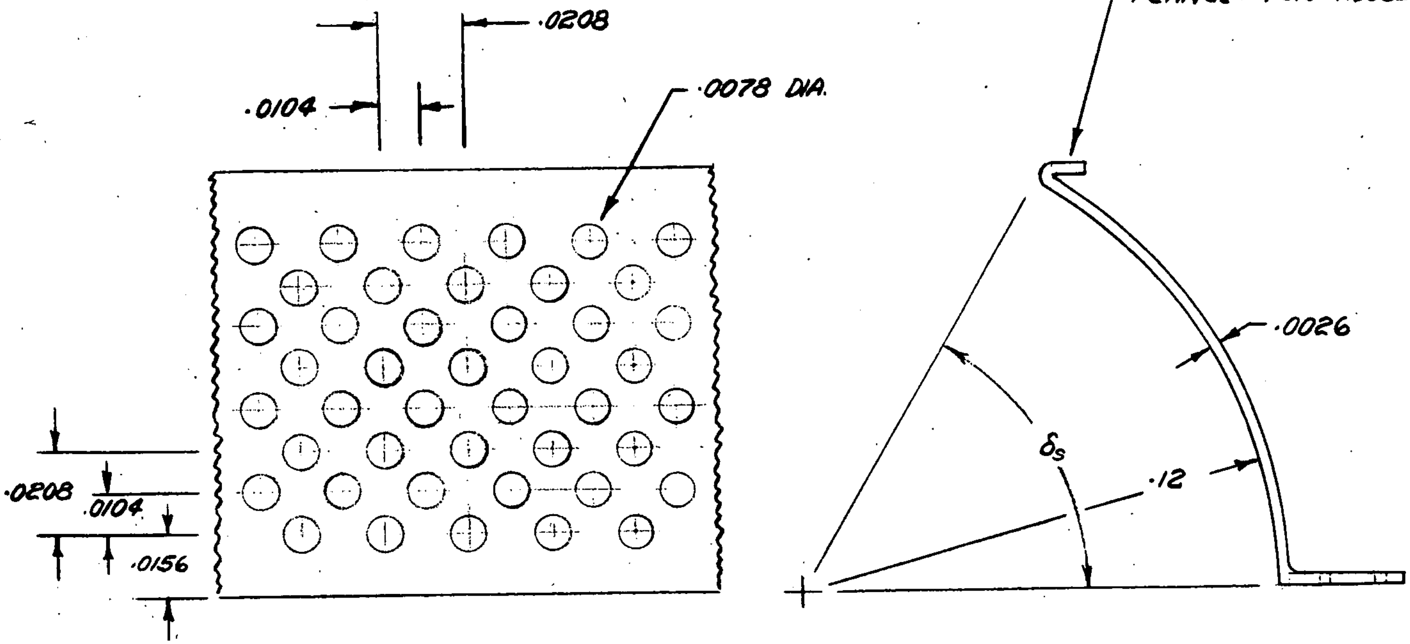


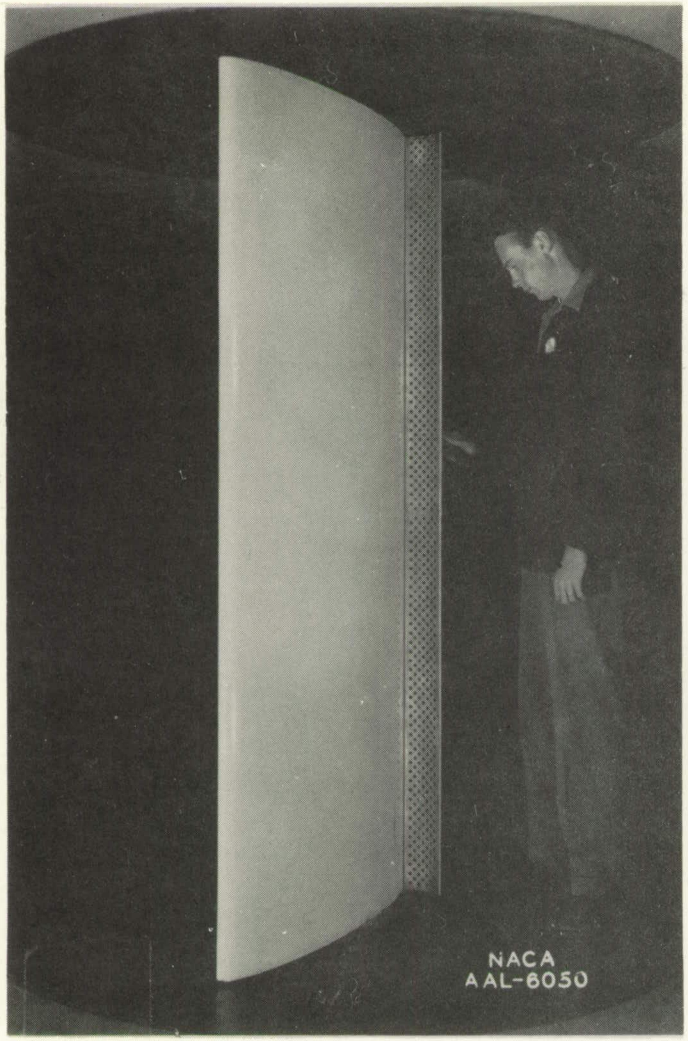
FIGURE 2 .- METHOD OF SEALING THE FLAP SLOT ON THE NACA 66,2-216 (a=0.6) AIRFOIL EQUIPPED WITH THE 0.25-CHORD SLOTTED FLAP.

NATIONAL ADVISORY
COMMITTEE FOR AERONAUTICS

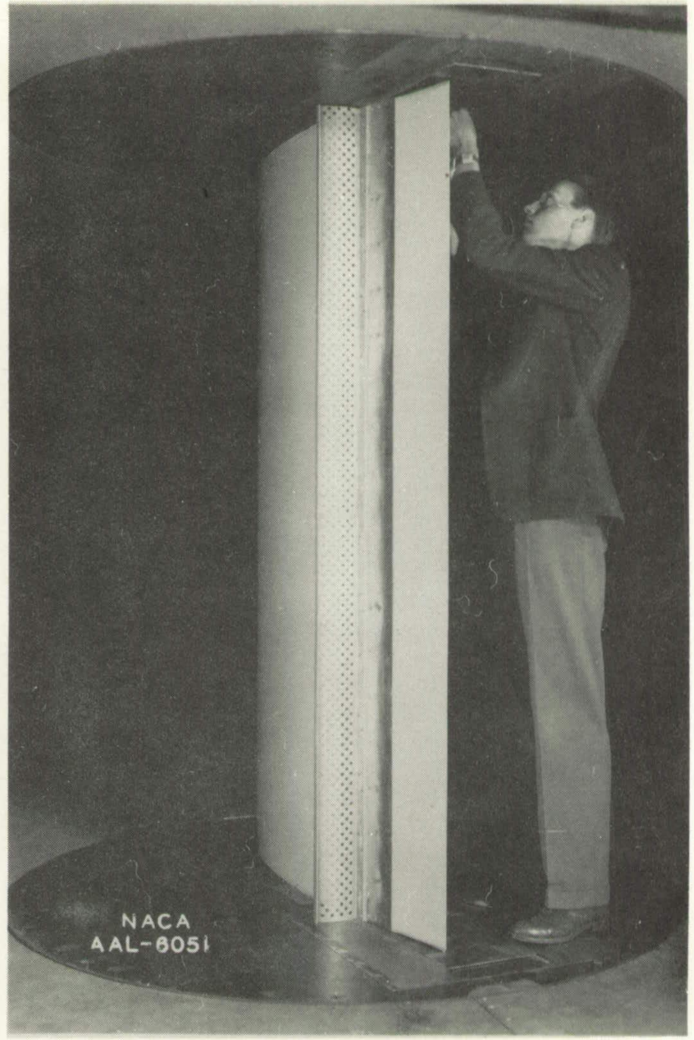


NOTE: ALL DIMENSIONS ARE IN FRACTIONS OF WING CHORD.

FIGURE 3.- DETAILS OF CONSTRUCTION OF THE SPOILERS TESTED ON THE NACA 66,2-216 (a = 0.6) AIRFOIL.

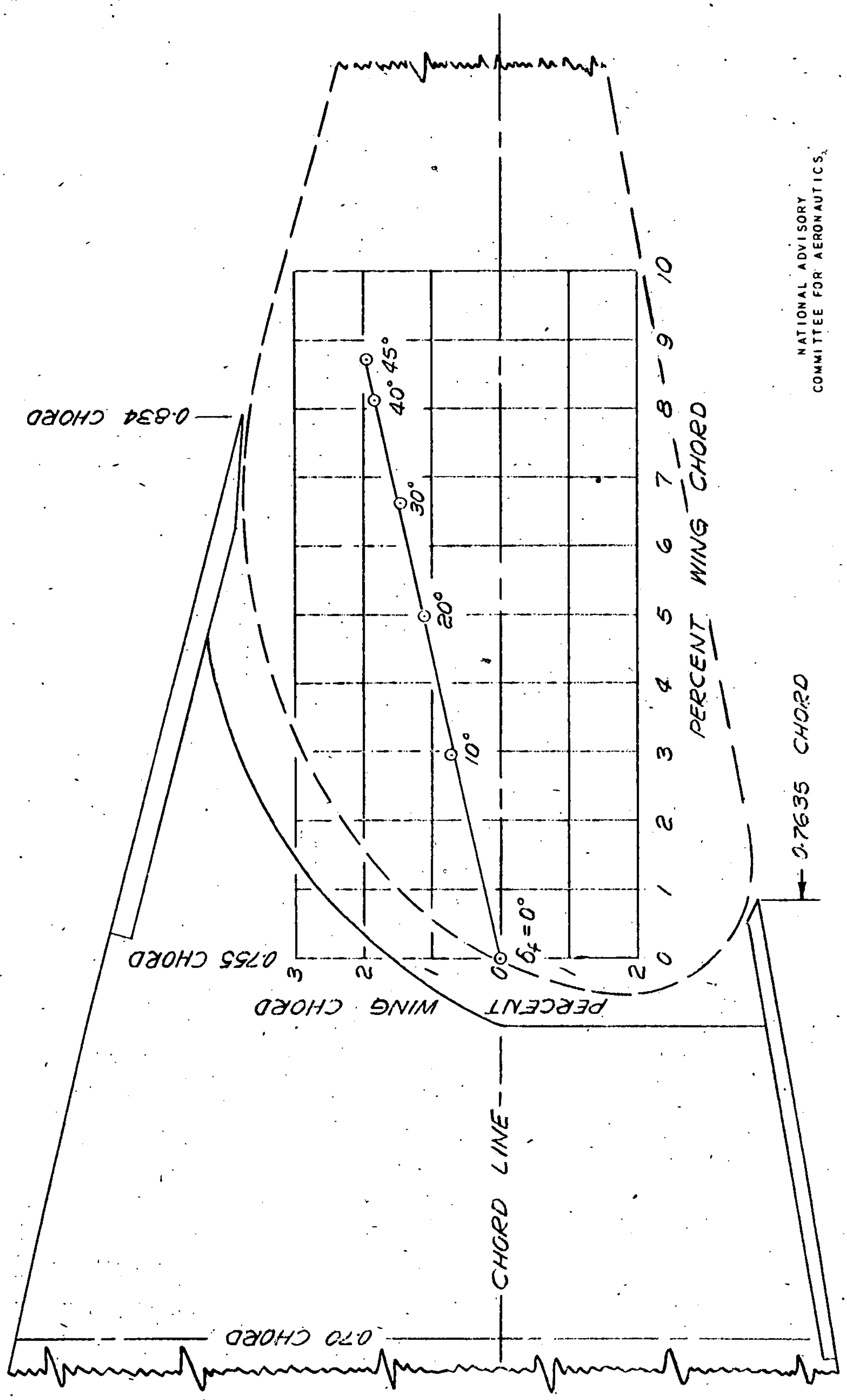


(a) Front view.



(b) Rear view.

Figure 4.- NACA 66,2-216 (a = 0.6) airfoil with the 45° spoiler on the upper surface.



NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

FIGURE 5.- PATH OF THE 0.25-CHORD SLOTTED FLAP USED ON THE NACA 66,2-216 (a=0.6) AIRFOIL.

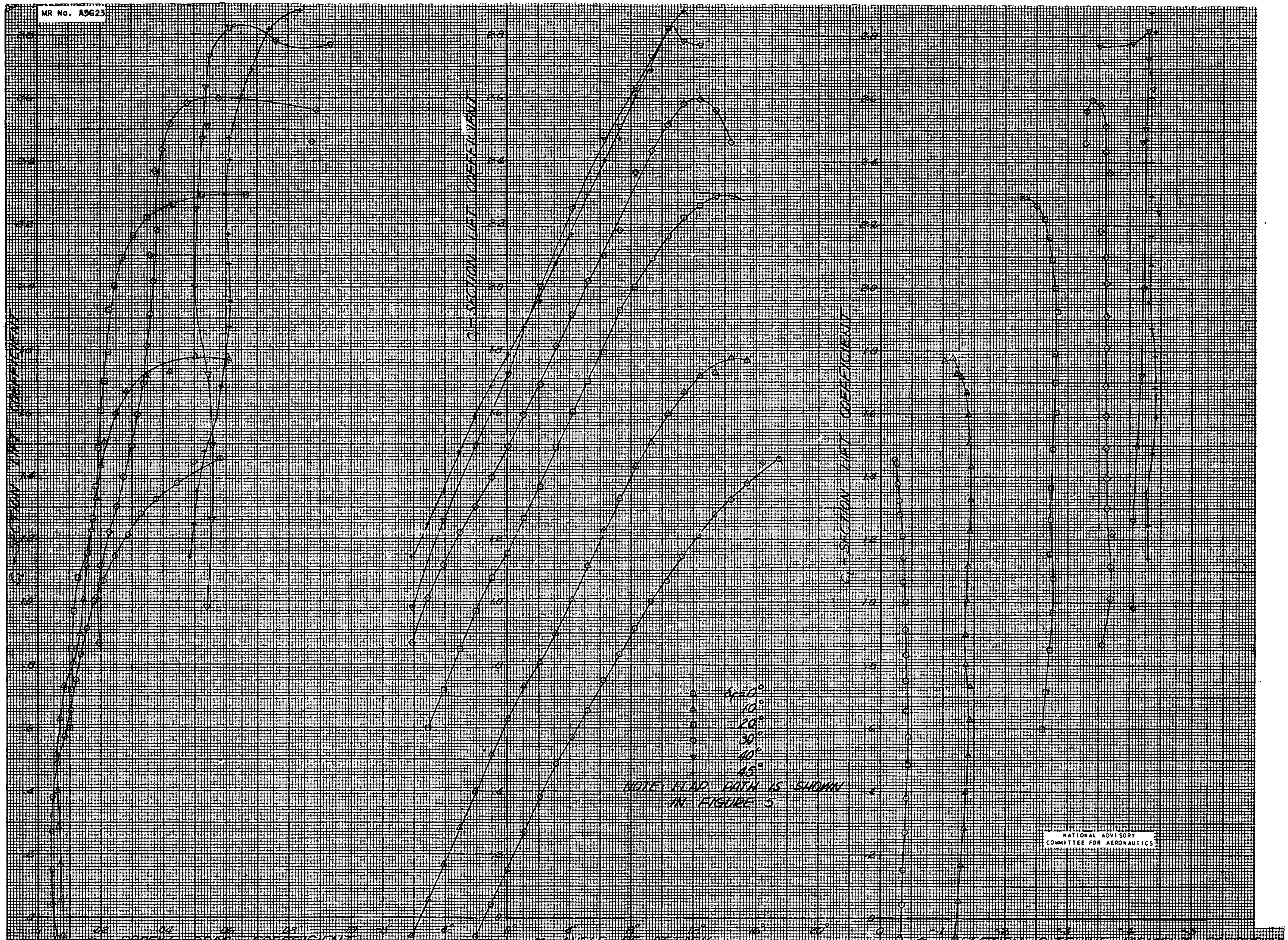


FIGURE 6 - SECTION AERODYNAMIC CHARACTERISTICS OF THE NACA 66,2-216 (a=0.6) AIRFOIL EQUIPPED WITH THE 0.25-CHORD FLAP AND SLOT B OF REFERENCE 4.

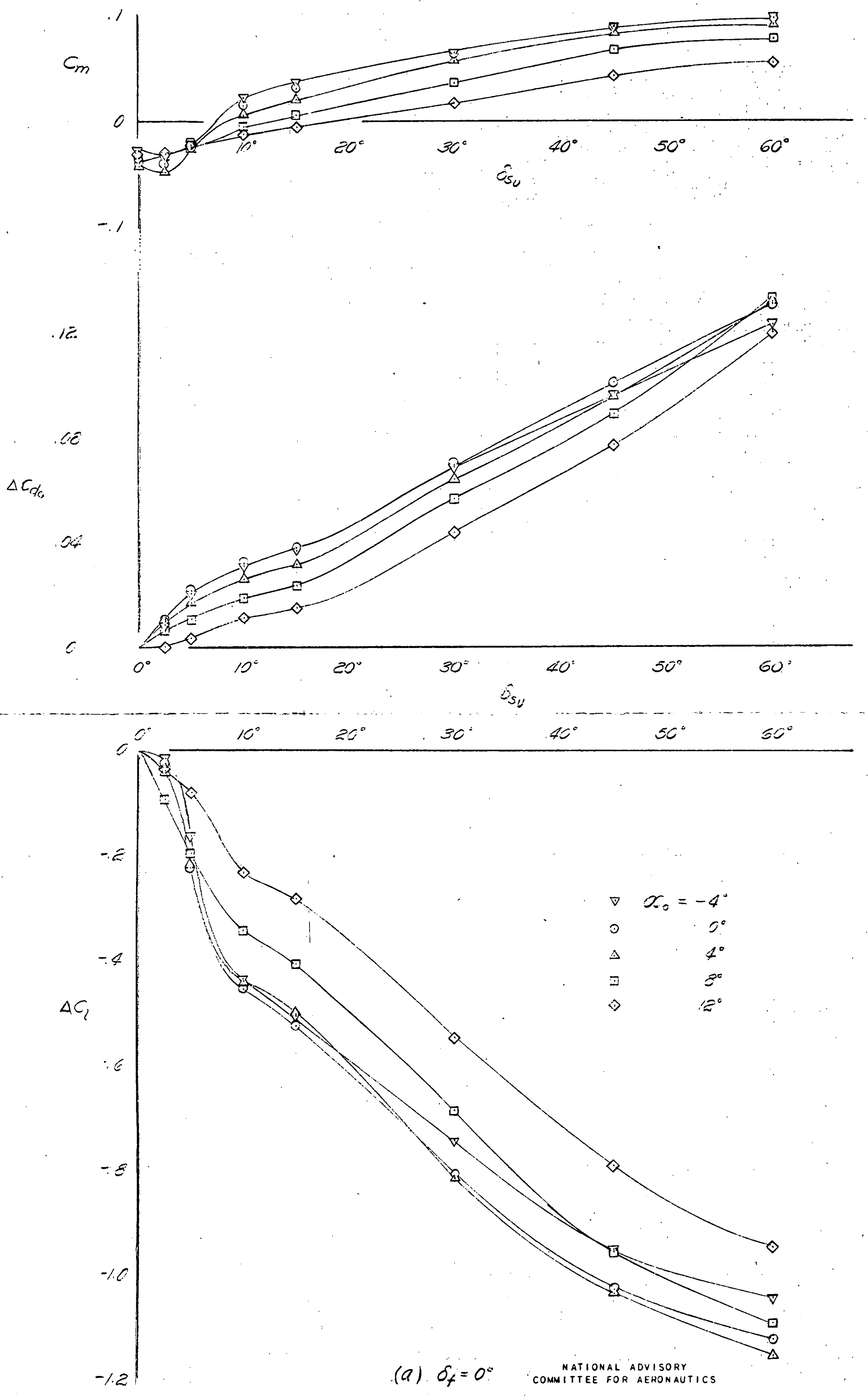
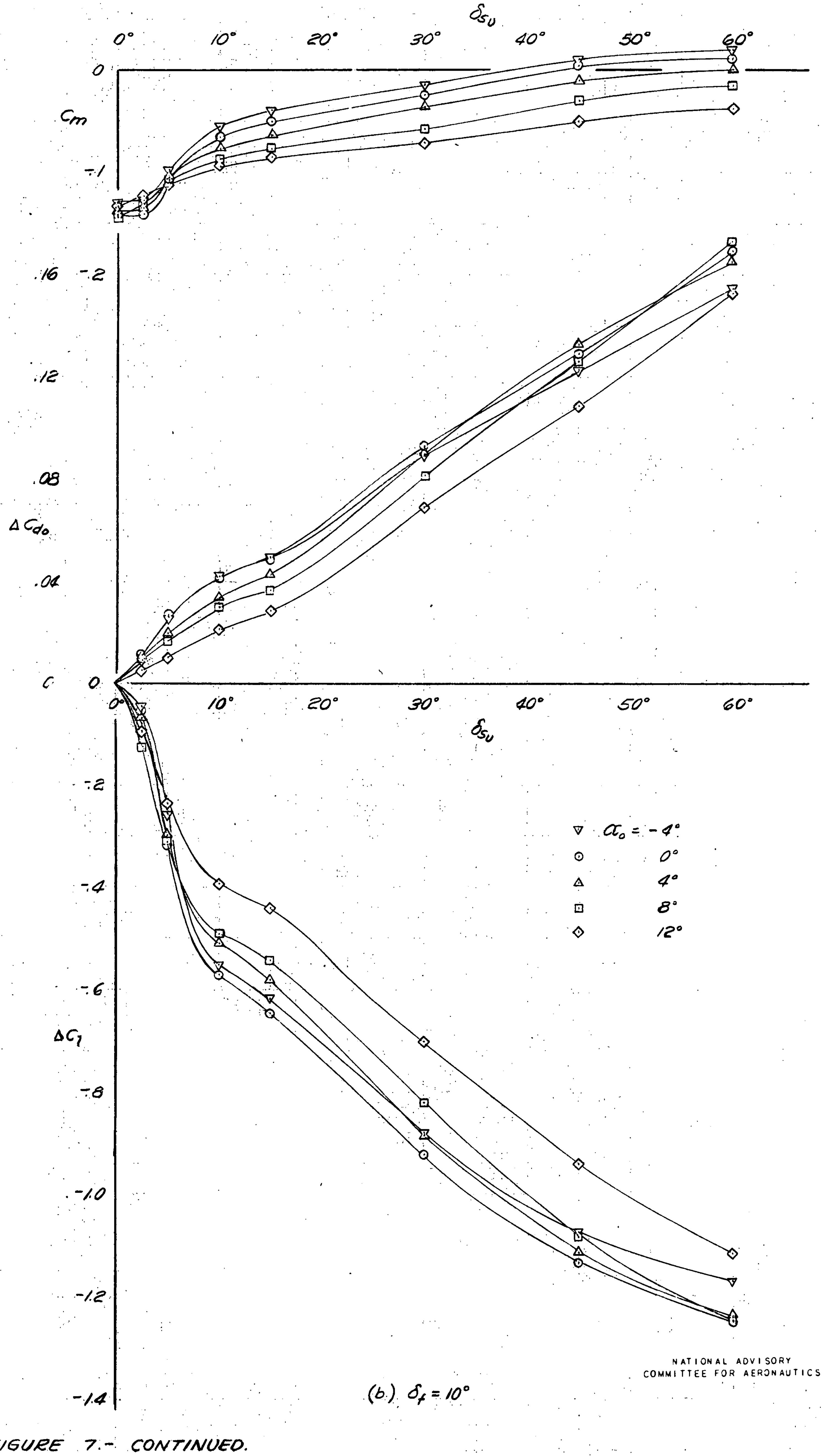


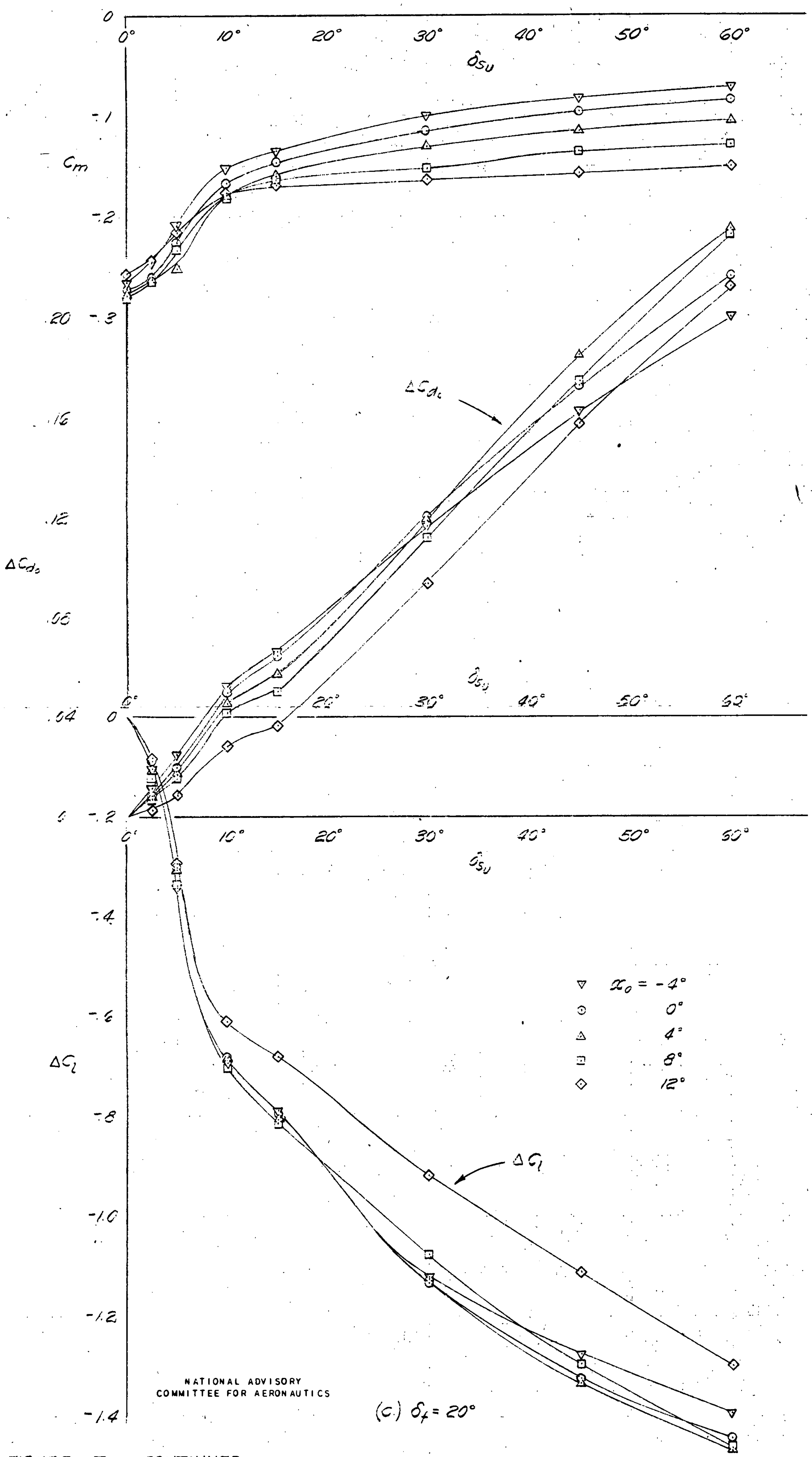
FIGURE 7.- EFFECT OF THE UPPER-SURFACE SPOILER ON THE SECTION CHARACTERISTICS OF THE NACA 66,2-216 (a=0.6) AIRFOIL EQUIPPED WITH THE 0.25-CHORD SLOTTED FLAP.



(b) $\delta_f = 10°$

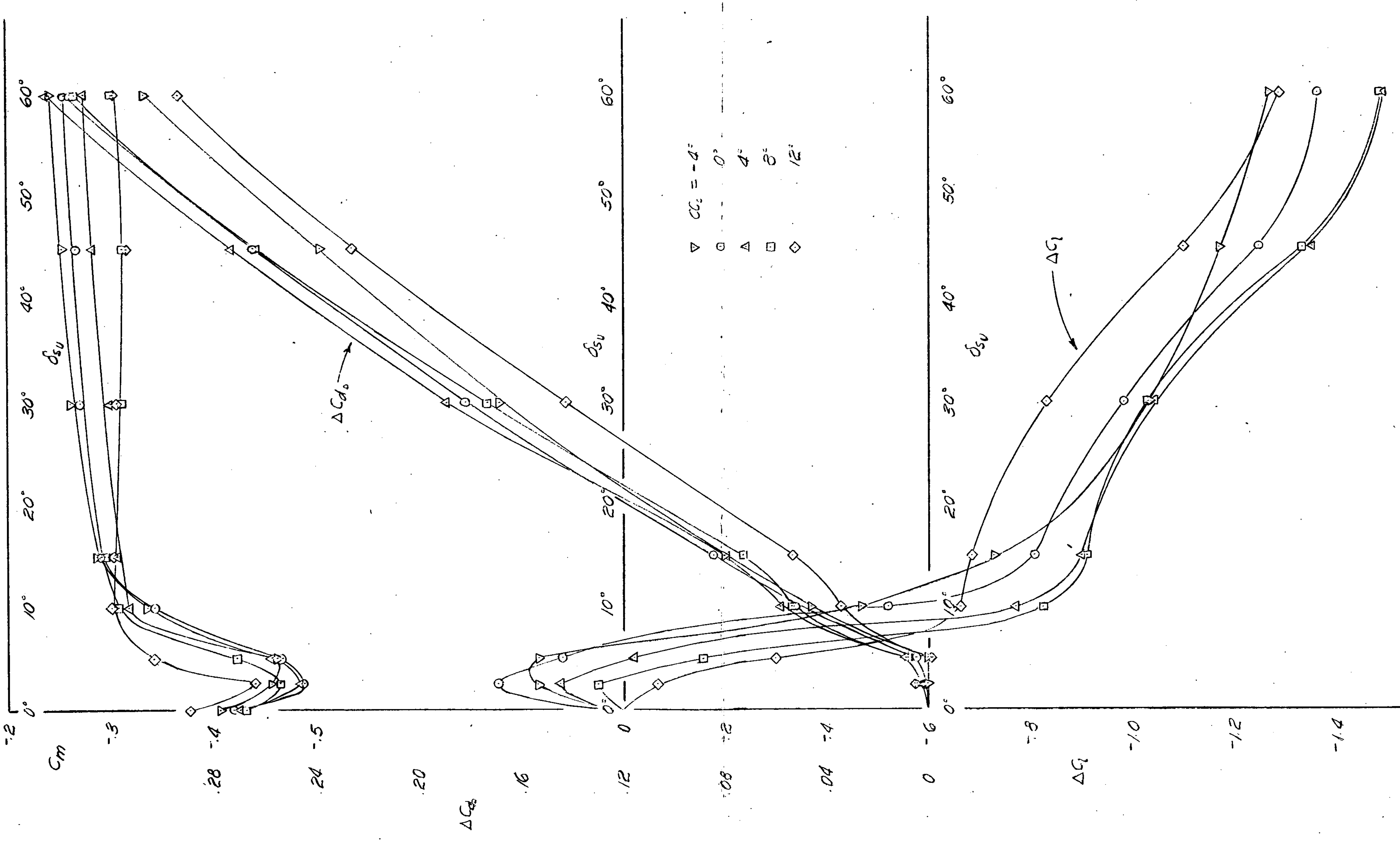
NATIONAL ADVISORY
COMMITTEE FOR AERONAUTICS

FIGURE 7.- CONTINUED.



(c) $\delta_f = 20°$

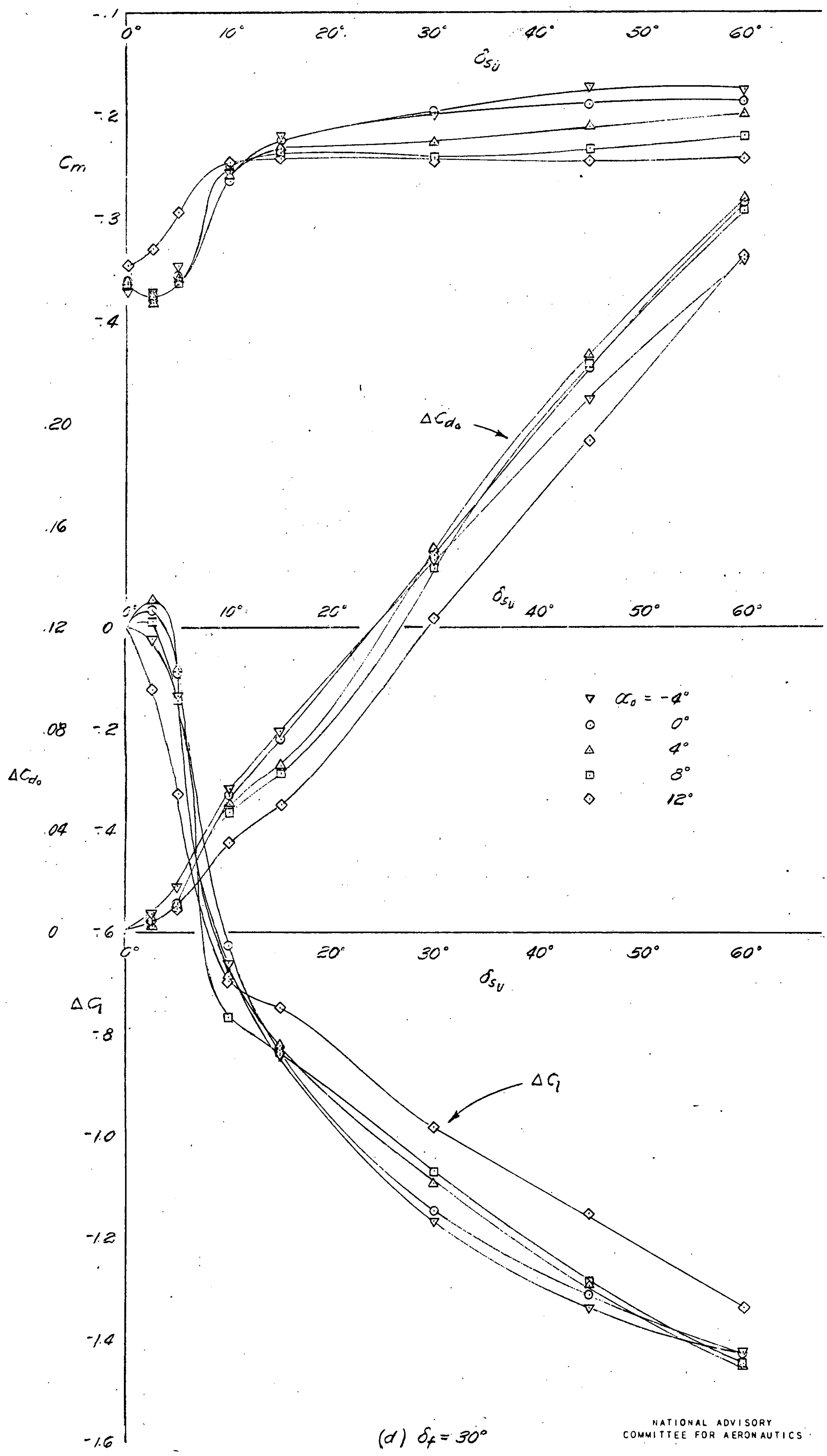
FIGURE 7.- CONTINUED.



(e) $\delta_f = 40°$

NATIONAL ADVISORY
COMMITTEE FOR AERONAUTICS

FIGURE 7.- CONTINUED.



(d) $\delta_f = 30°$

FIGURE 7.- CONTINUED.

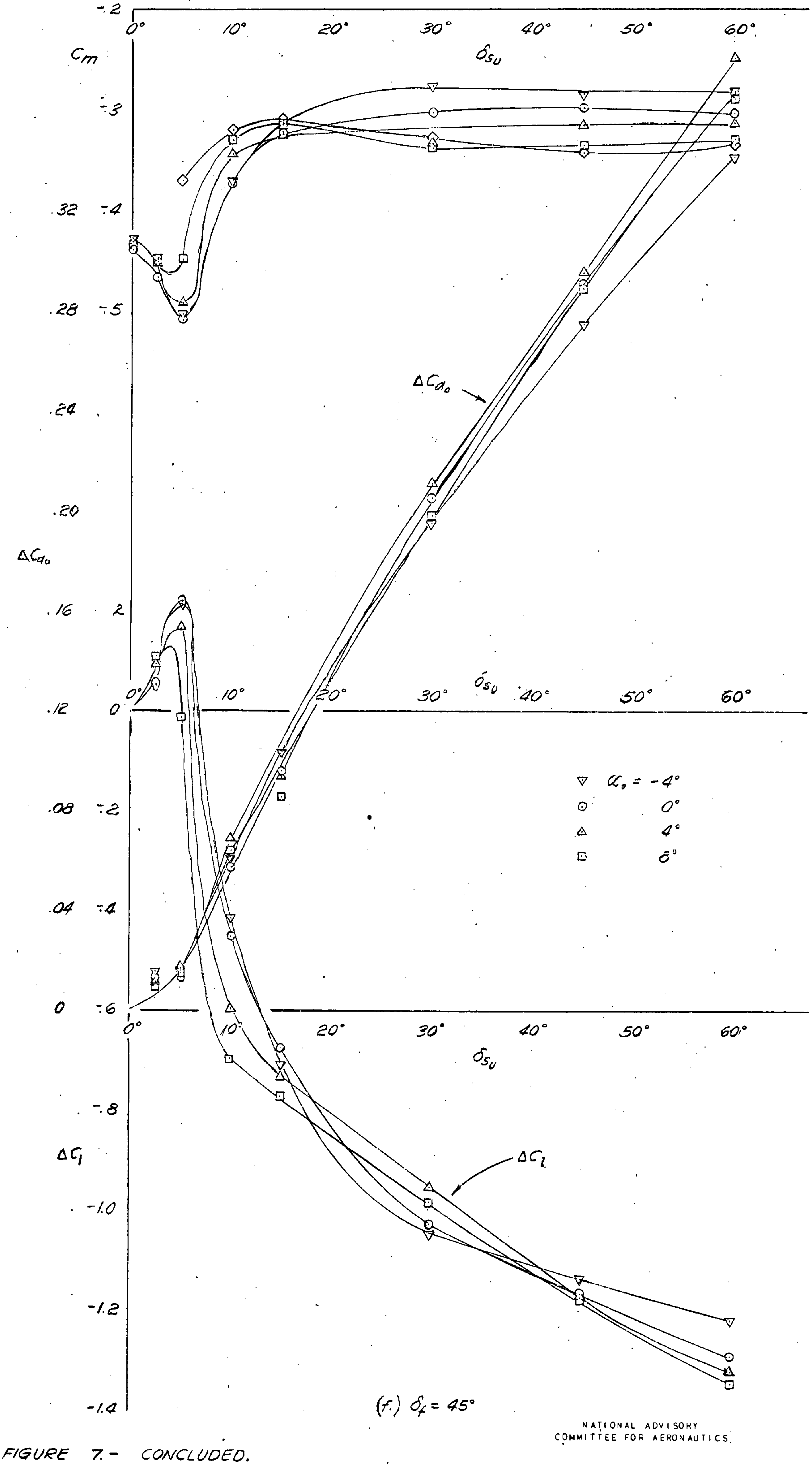
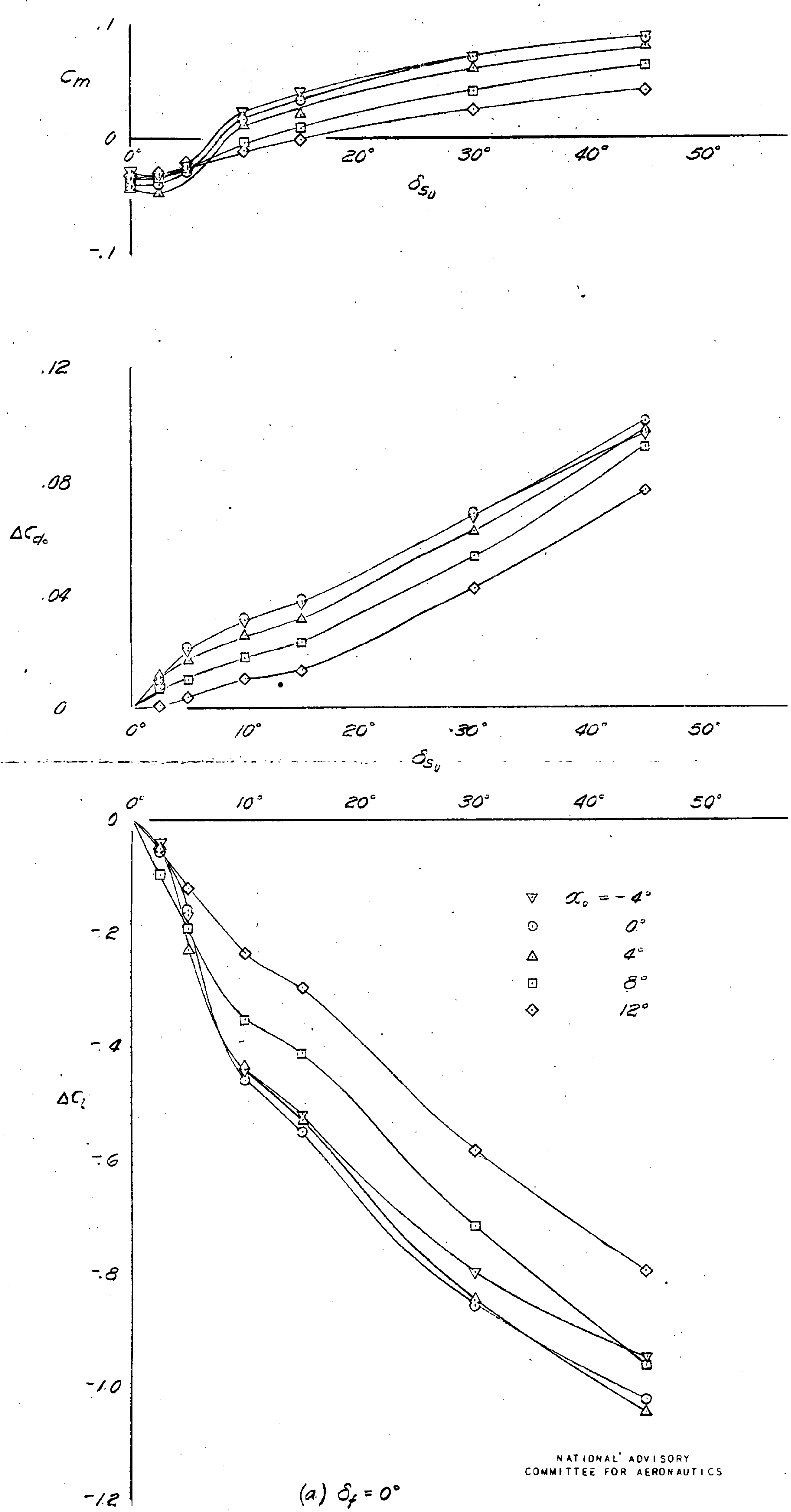
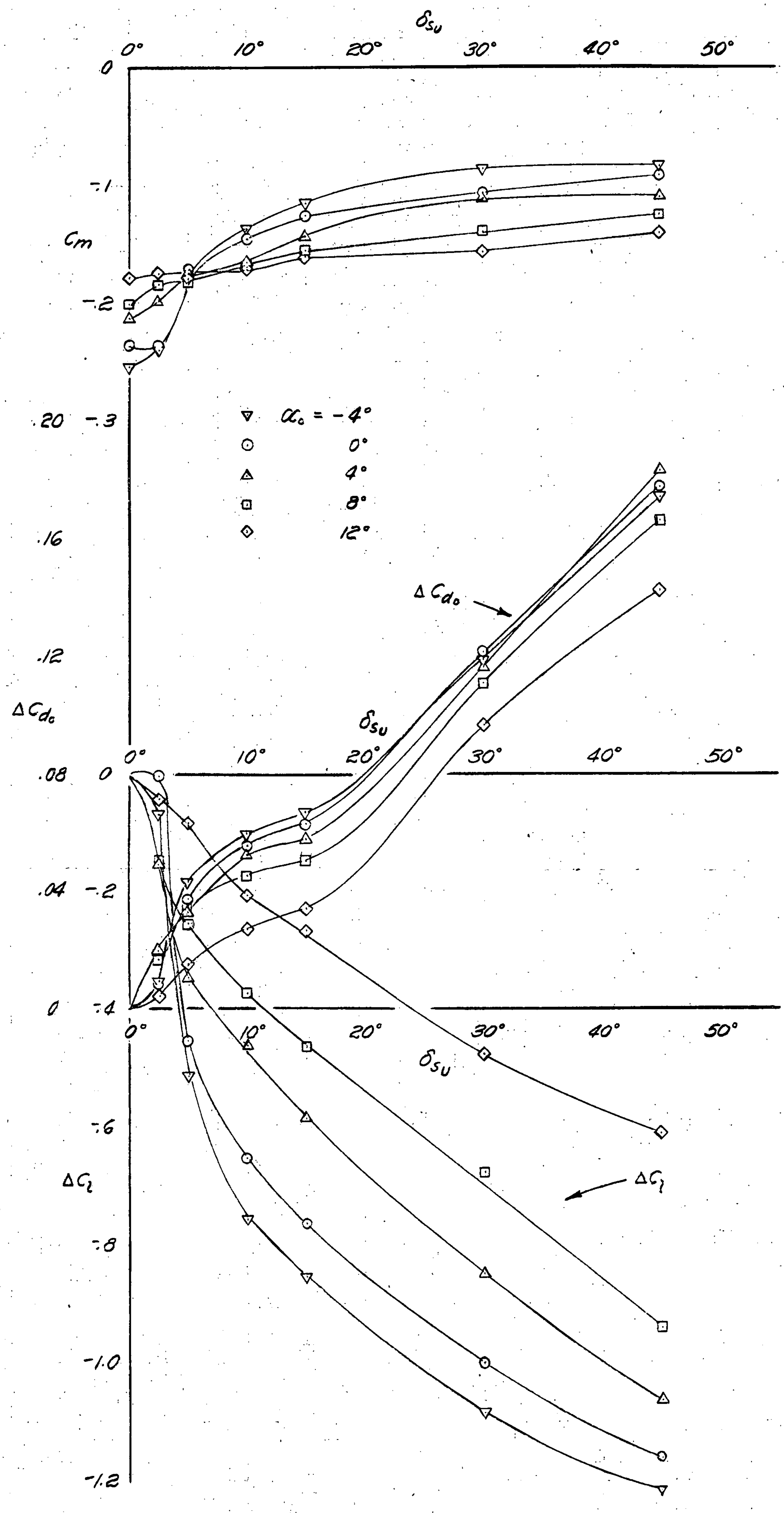


FIGURE 7.- CONCLUDED.



(a) $\delta_f = 0°$

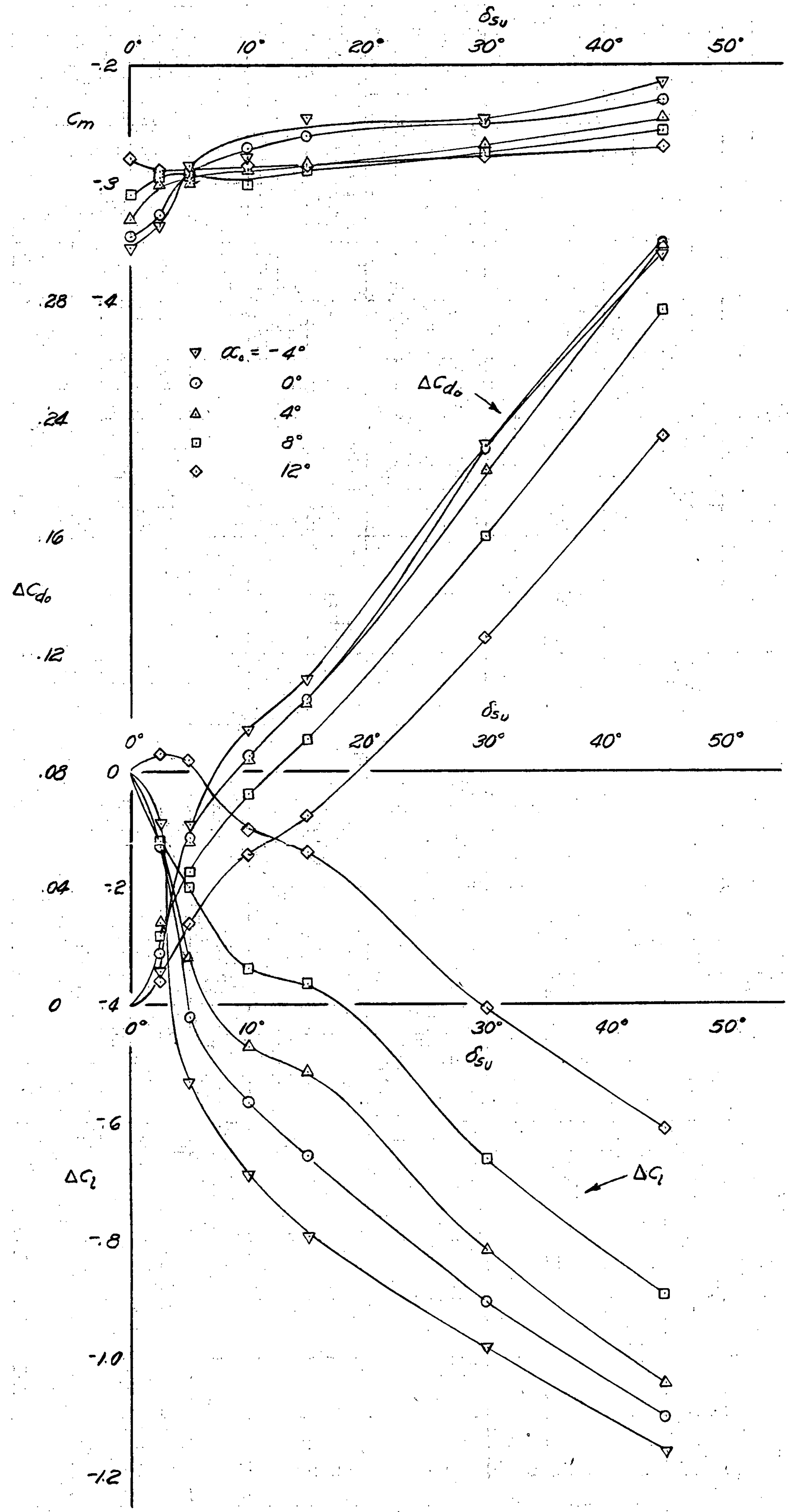
FIGURE 8.- EFFECT OF THE UPPER-SURFACE SPOILER ON THE SECTION CHARACTERISTICS OF THE NACA 66,2-216 (a=0.6) AIRFOIL EQUIPPED WITH THE 0.25-CHORD SLOTTED FLAP WITH THE FLAP SLOT SEALED.



(b.) $\delta_f = 20°$

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

FIGURE 8.- CONTINUED.



(c) $\delta_f = 40°$

NATIONAL ADVISORY
COMMITTEE FOR AERONAUTICS

FIGURE 8.- CONCLUDED.

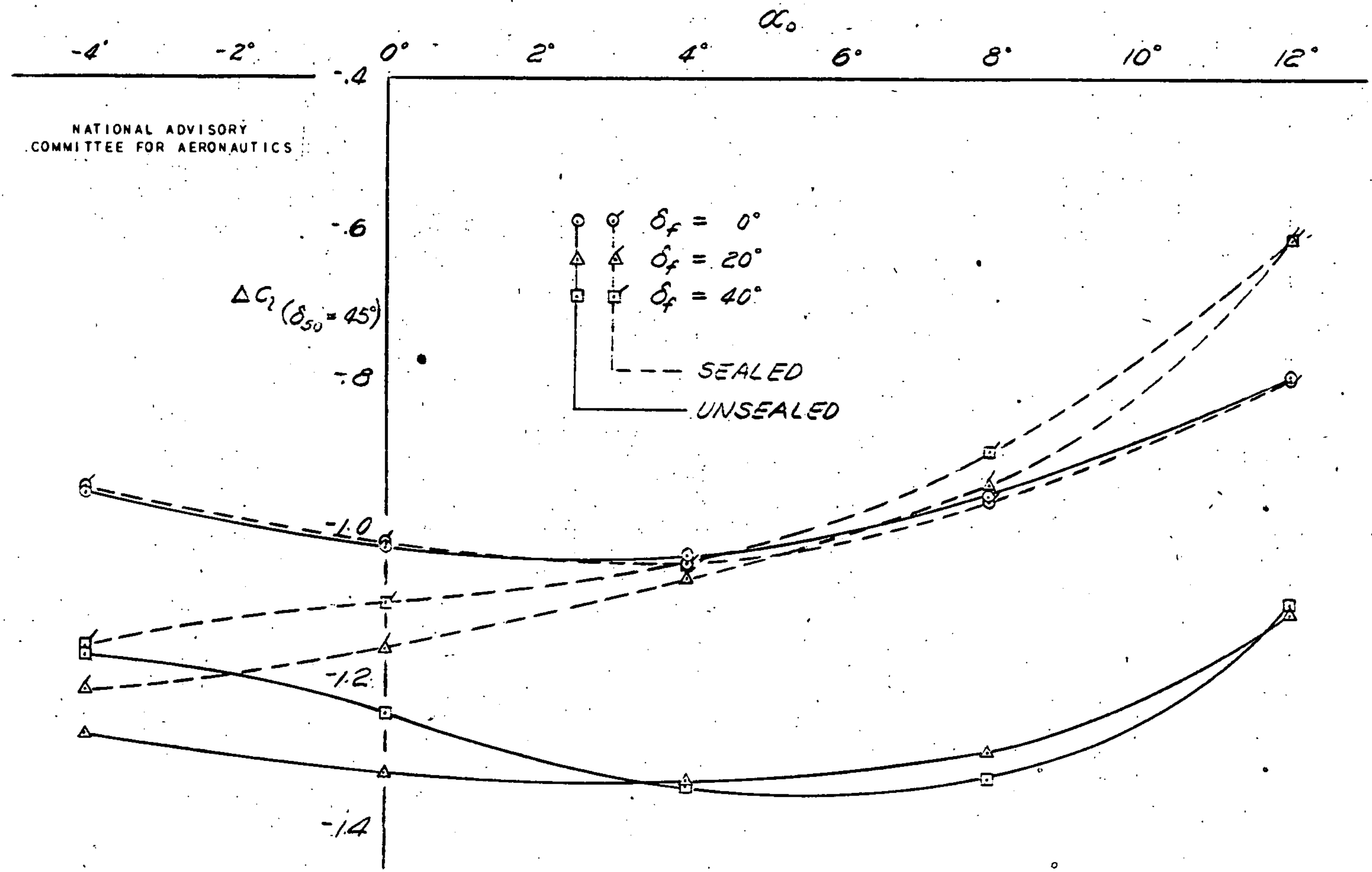


FIGURE 9.- EFFECT OF THE FLAP-SLOT SEAL ON THE EFFECTIVENESS OF THE UPPER-SURFACE SPOILER ON THE NACA 66,2-216 (a=0.6) AIRFOIL EQUIPPED WITH THE 0.25-CHORD SLOTTED FLAP.

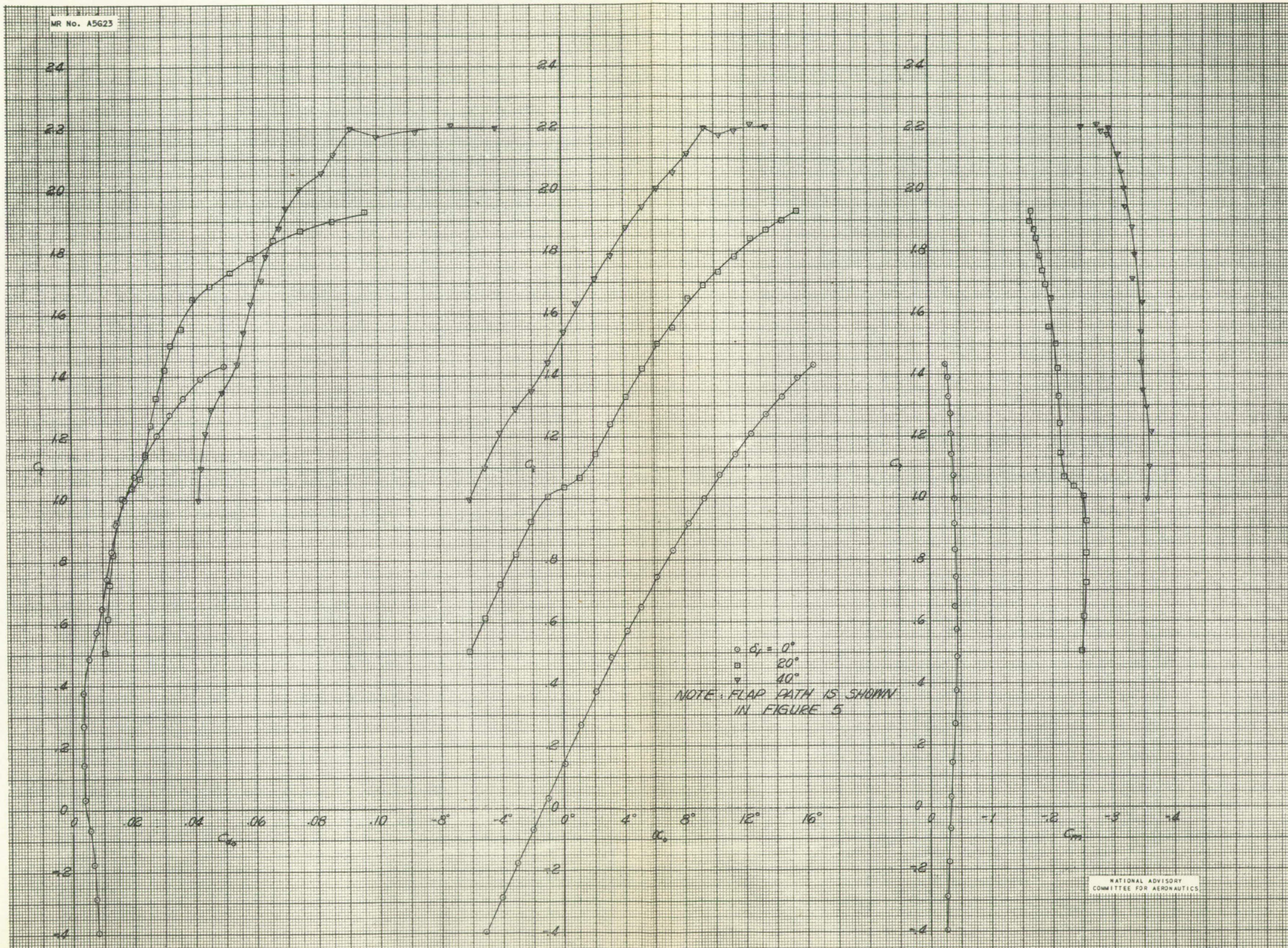


FIGURE 10 - AERODYNAMIC CHARACTERISTICS OF THE NACA 66,2-216 (a=0.6) AIRFOIL EQUIPPED WITH THE 0.25-CHORD FLAP WITH THE SLOT SEALED

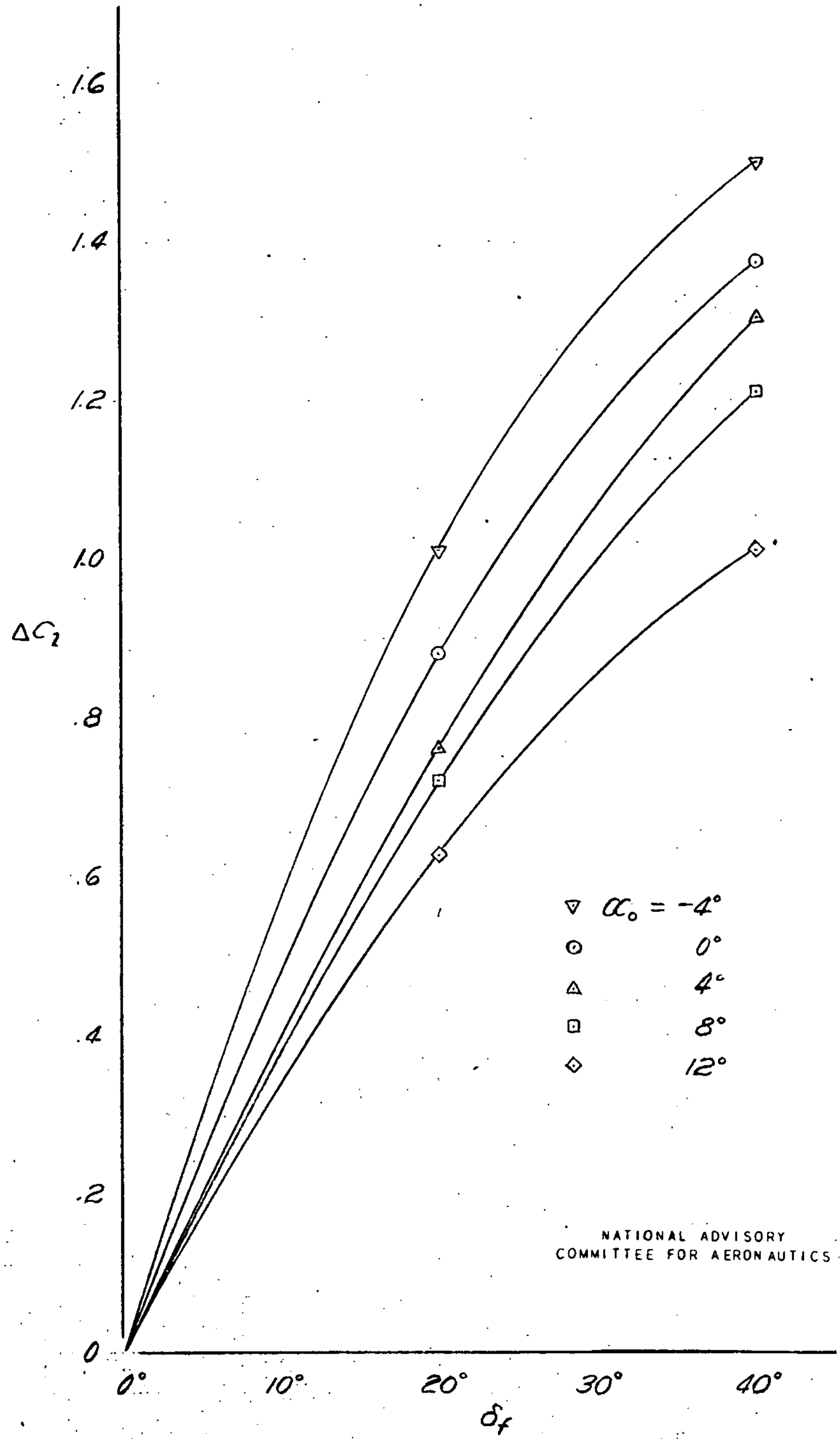


FIGURE 11.- VARIATION OF THE LIFT-COEFFICIENT INCREMENT WITH DEFLECTION OF THE 0.25-CHORD SLOTTED FLAP ON THE NACA 66,2-216 (a=0.6) AIRFOIL WITH THE SLOT SEALED.

A-92

MR No. A5G23

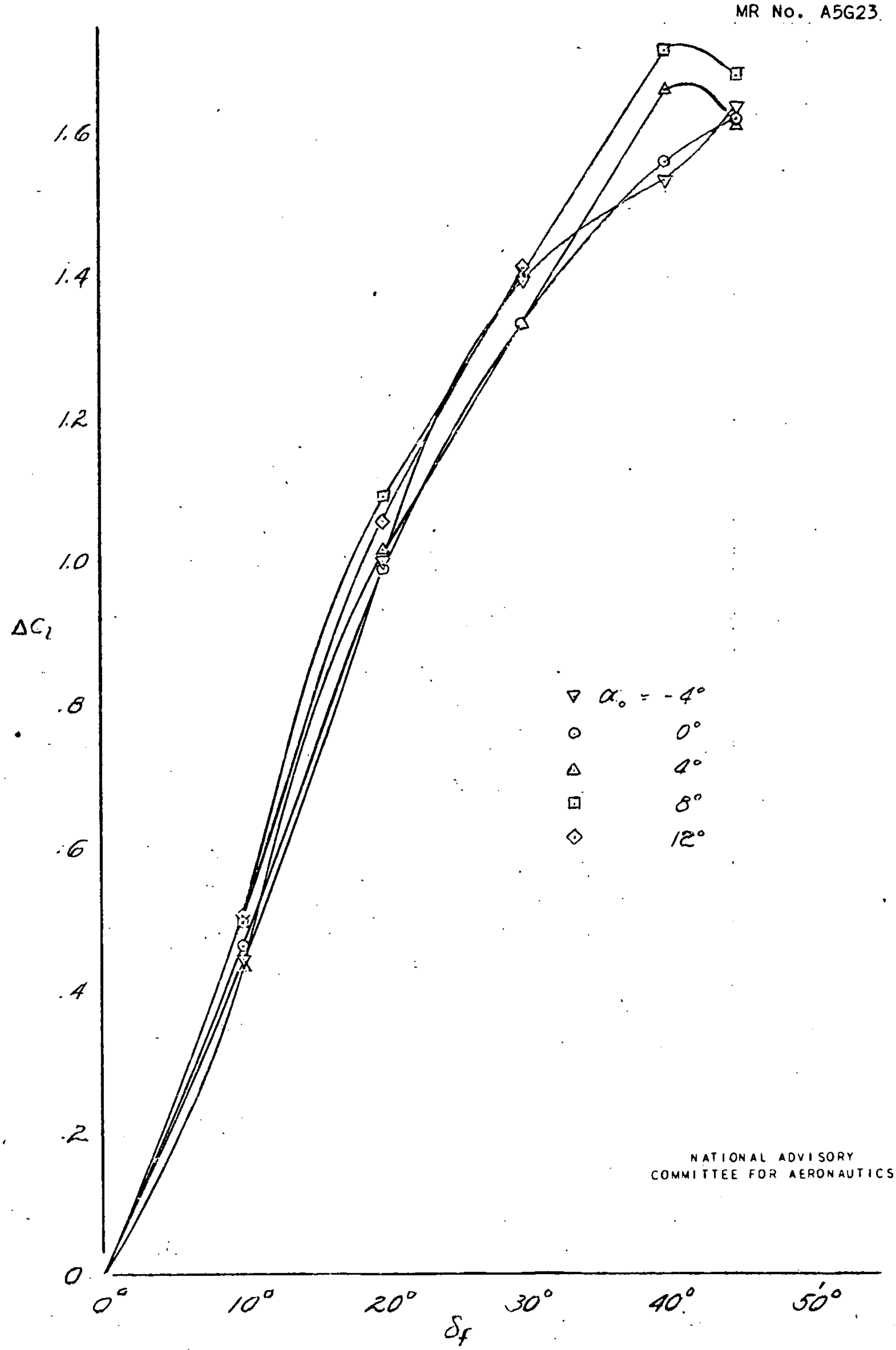


FIGURE 12.- VARIATION OF THE LIFT-COEFFICIENT INCREMENT WITH DEFLECTION OF THE 0.25-CHORD SLOTTED FLAP ON THE NACA 66,2-216 (a=0.6) AIRFOIL WITH THE SLOT UNSEALED.

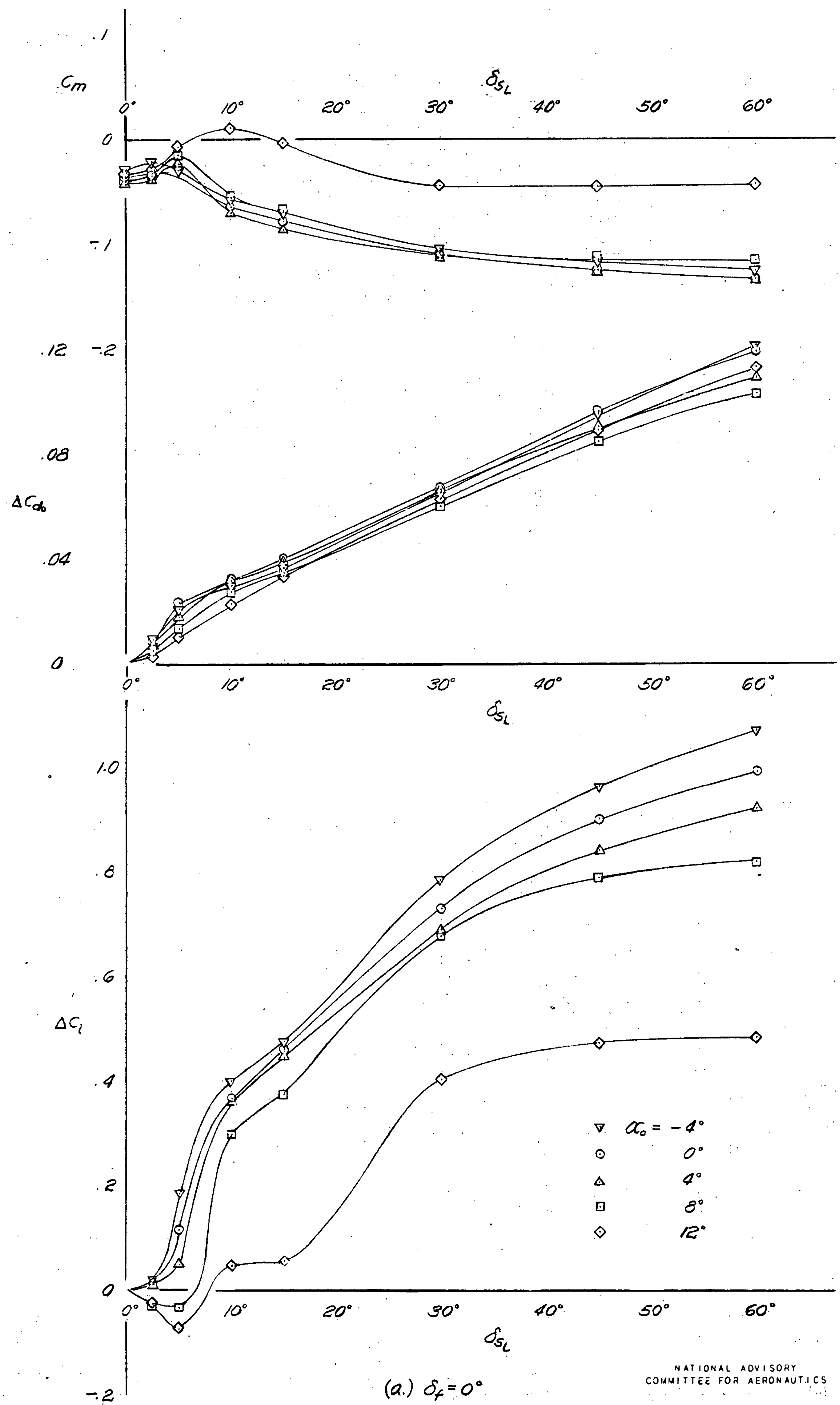
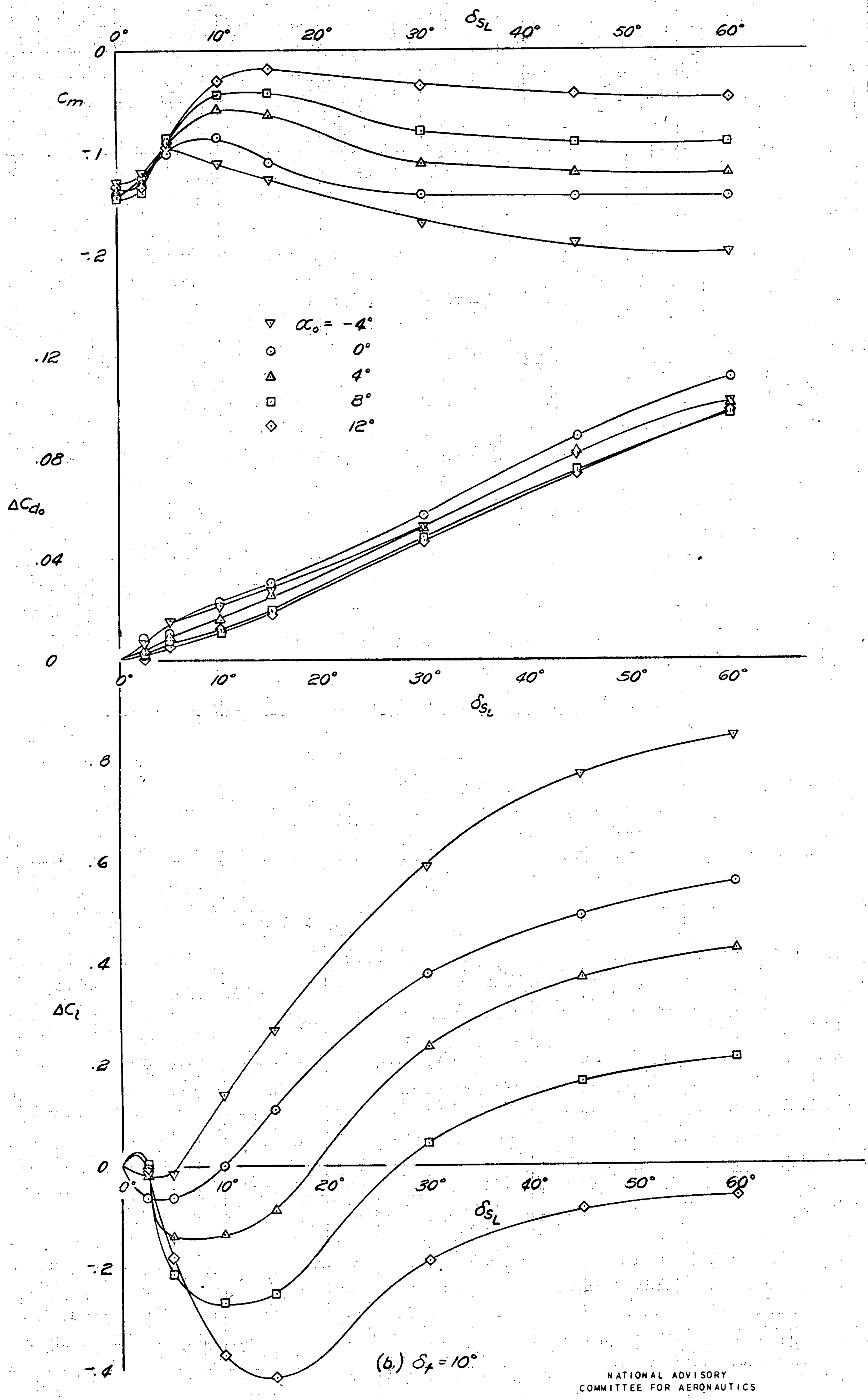
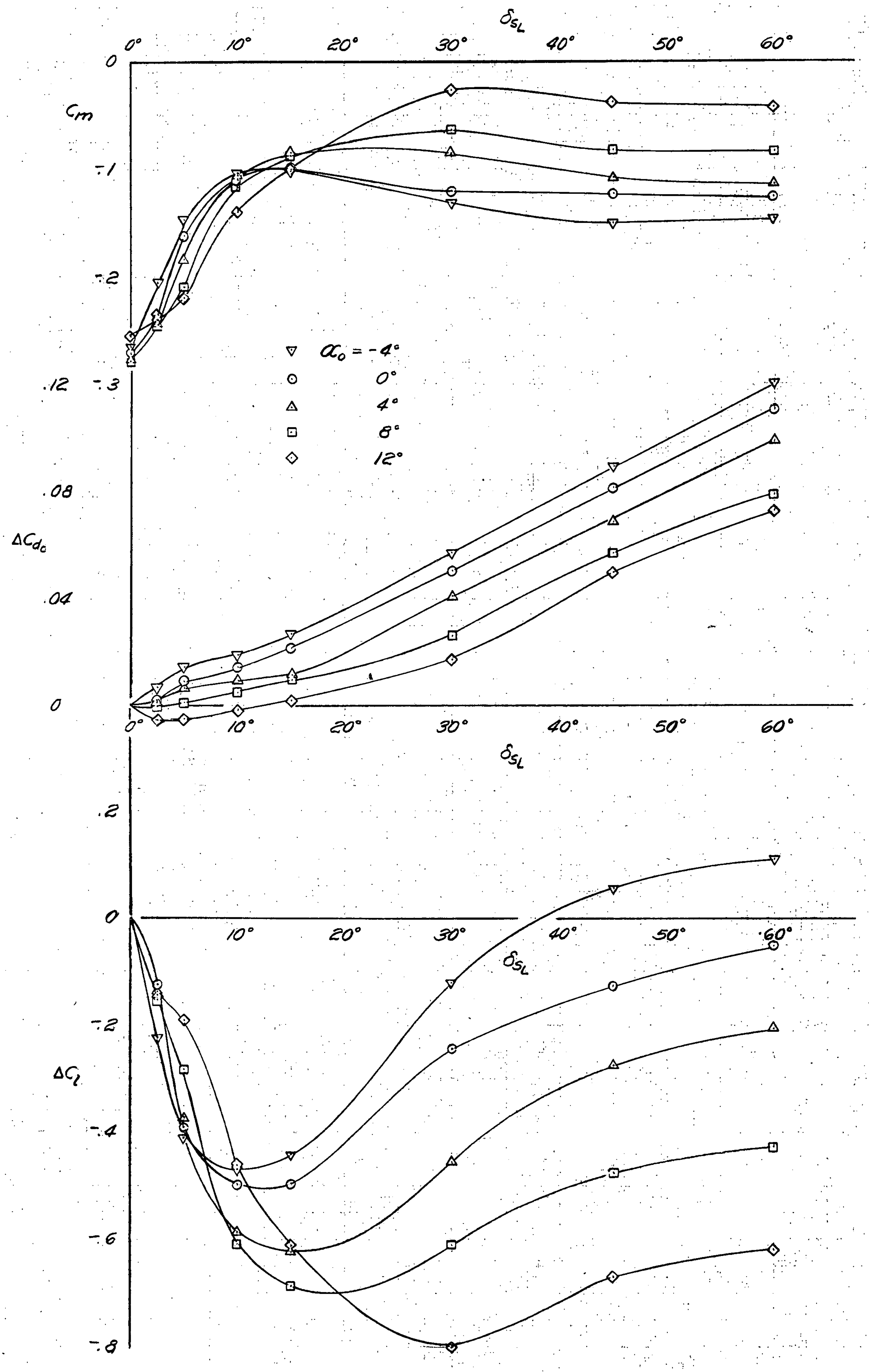


FIGURE 13.- EFFECT OF THE LOWER-SURFACE SPOILER ON THE SECTION CHARACTERISTICS OF THE NACA 66,2-216 (a=0.6) AIRFOIL EQUIPPED WITH THE 0.25-CHORD SLOTTED FLAP.



NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

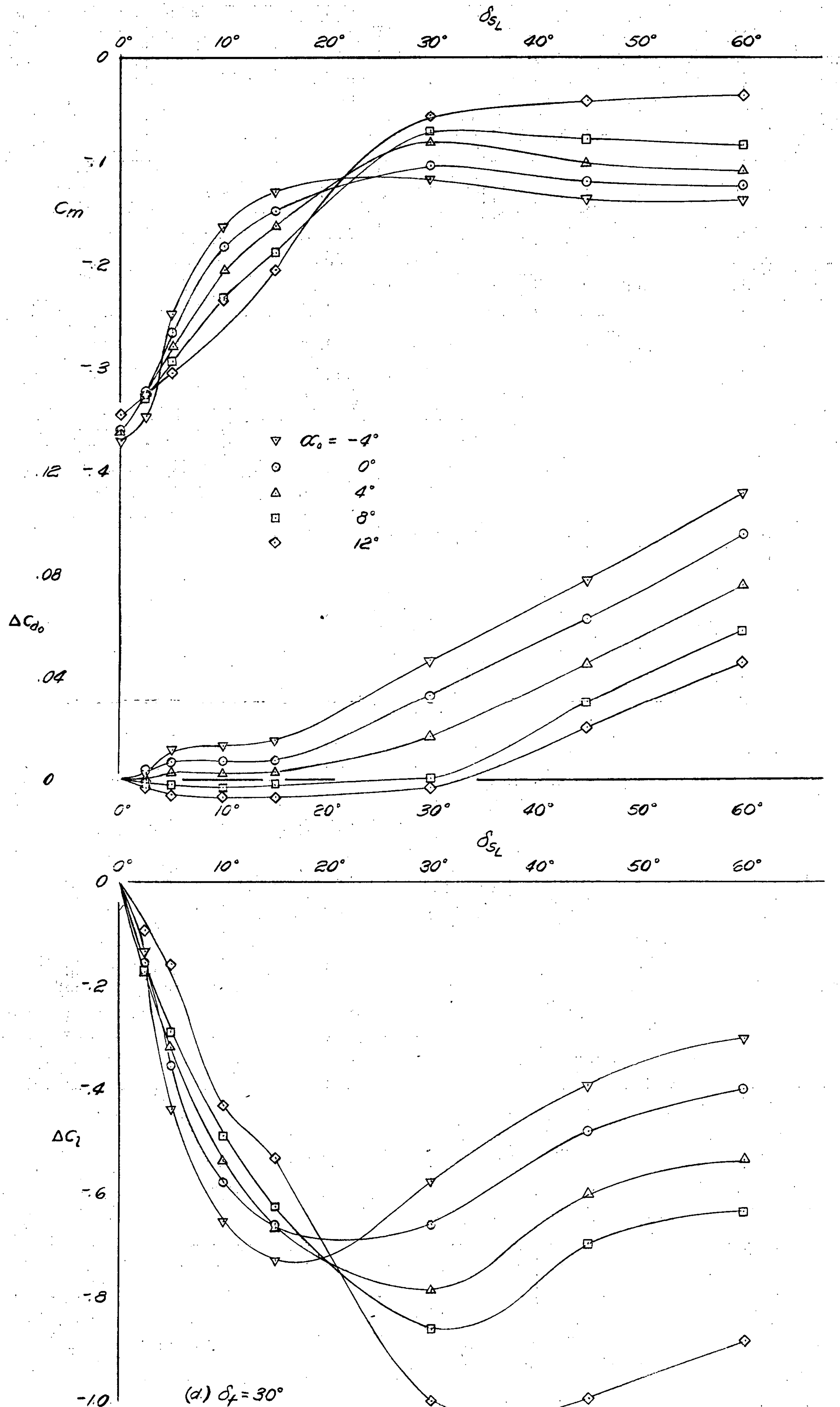
FIGURE 13.- CONTINUED.



(c) $\delta_f = 20°$

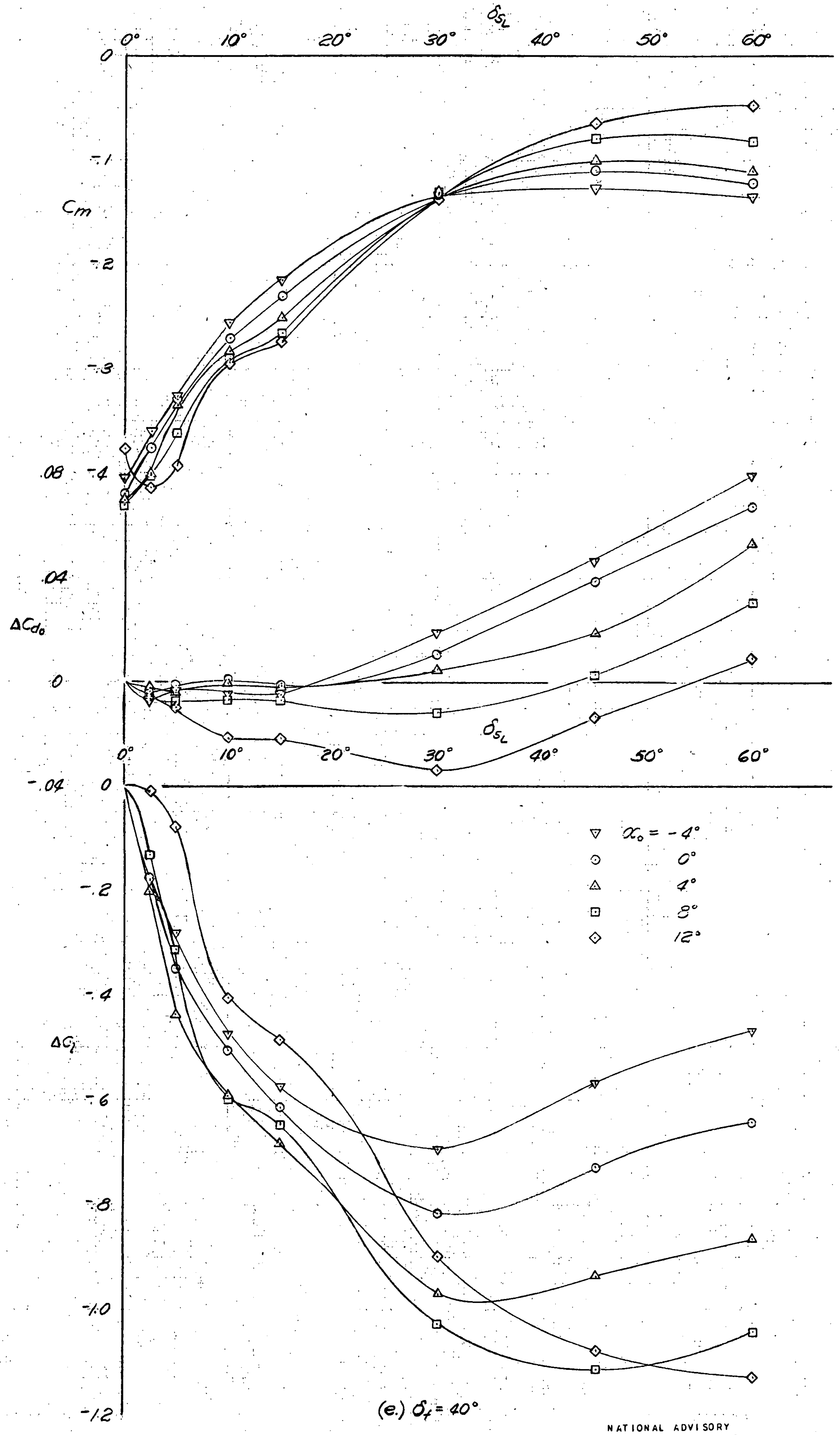
NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

FIGURE 13.- CONTINUED.



NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

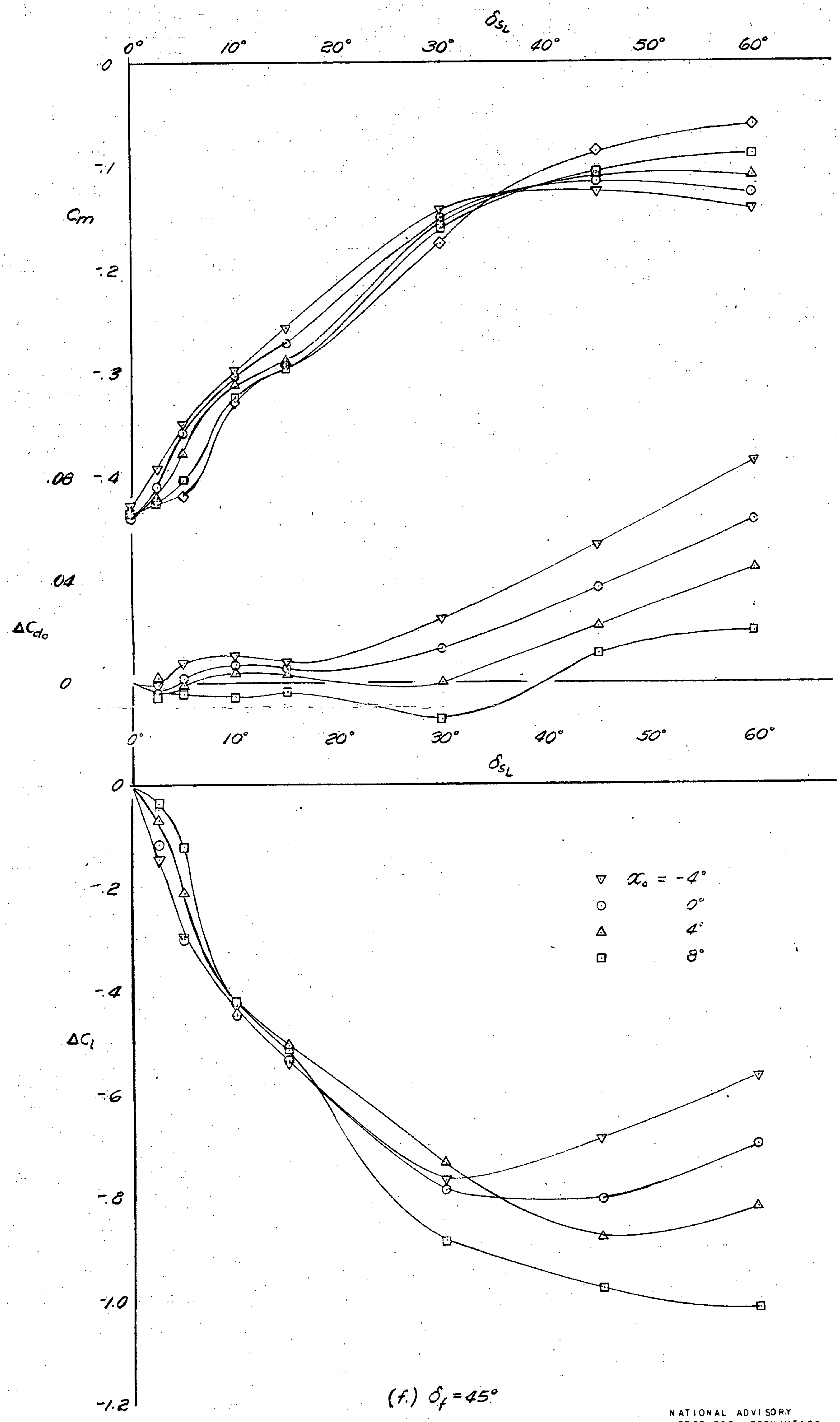
FIGURE 13.- CONTINUED.



(e.) $\delta_f = 40°$

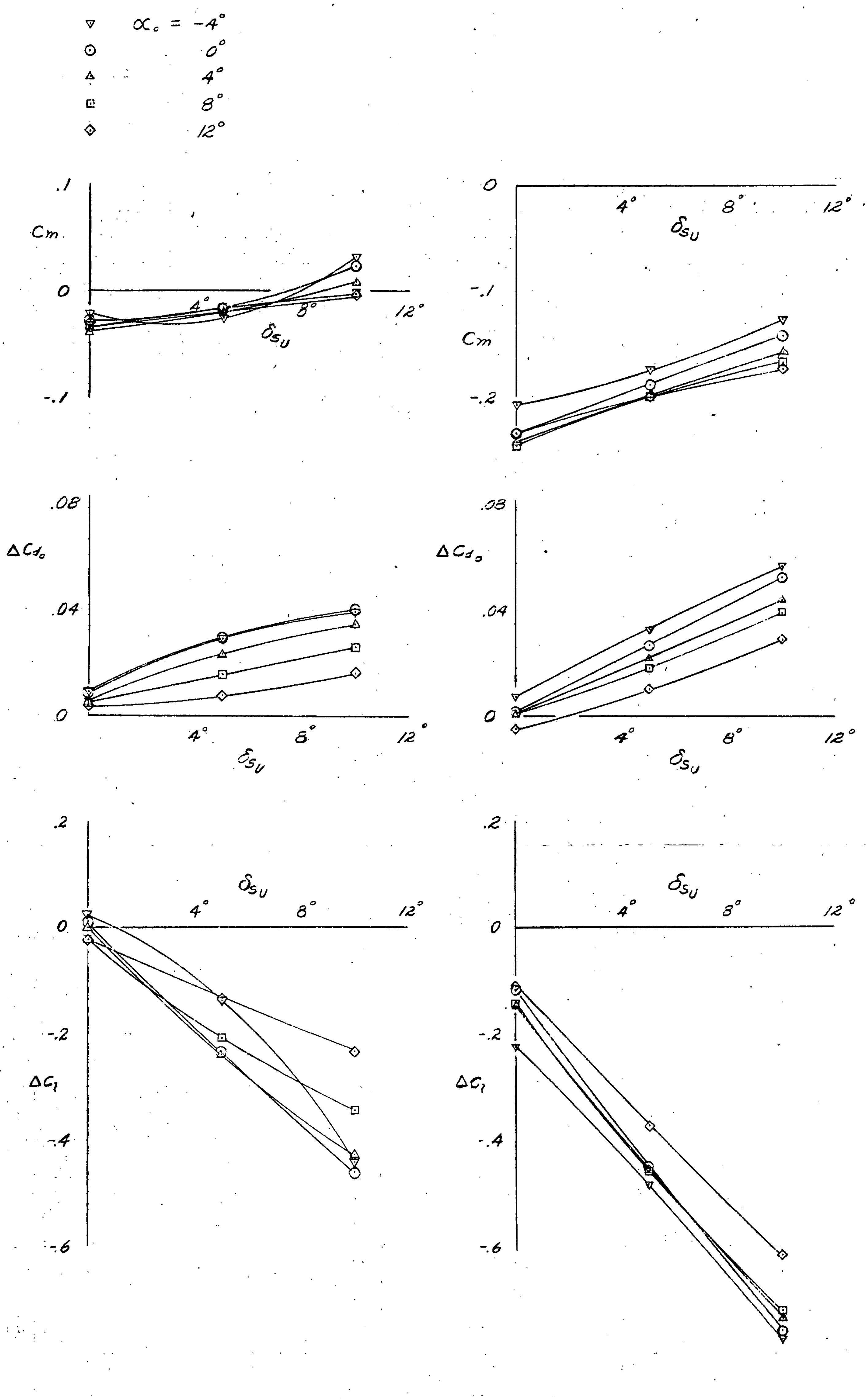
NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

FIGURE 13.- CONTINUED.



NATIONAL ADVISORY
COMMITTEE FOR AERONAUTICS

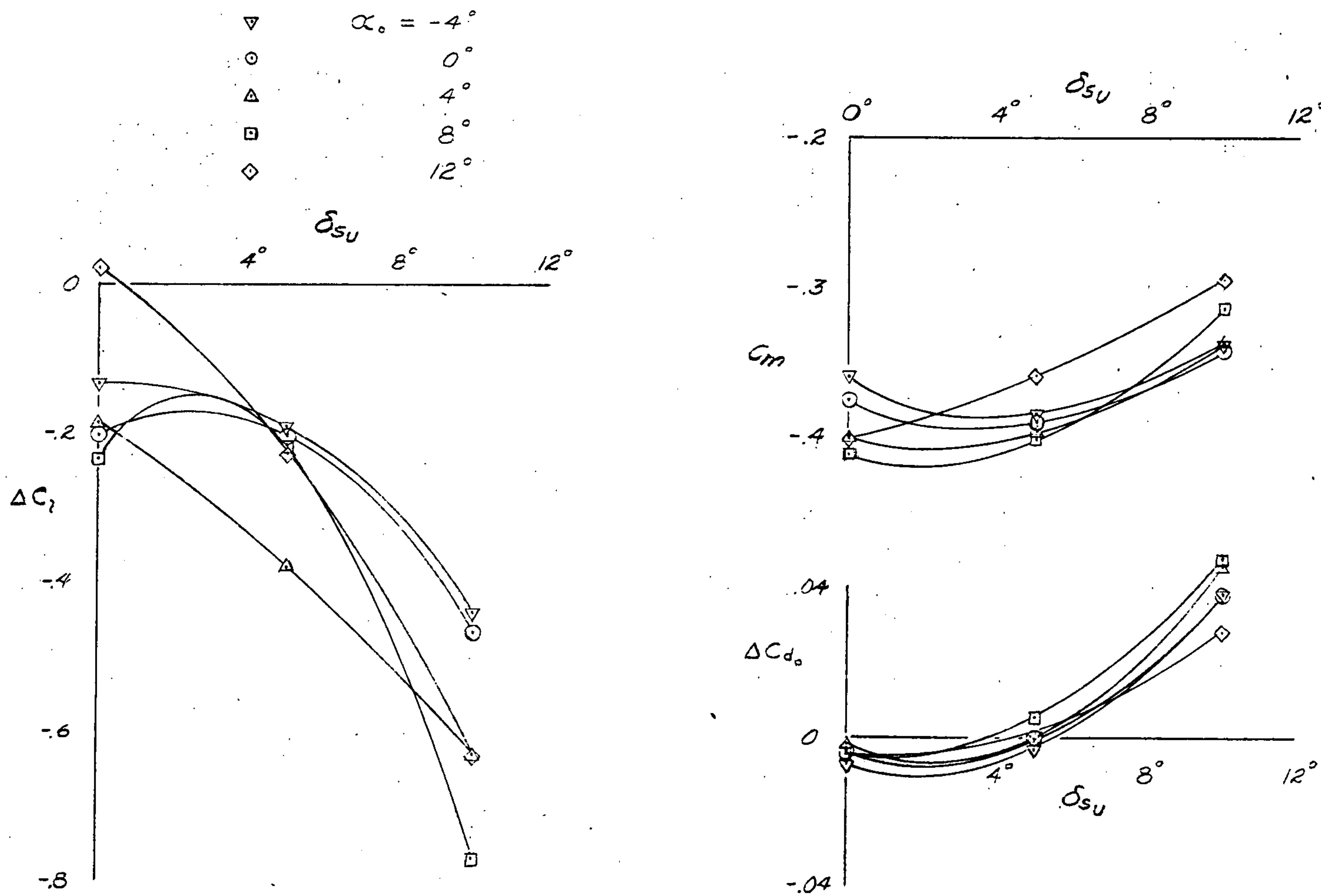
FIGURE 13. - CONCLUDED.



(a.) $\delta_f = 0°$ (b.) $\delta_f = 20°$

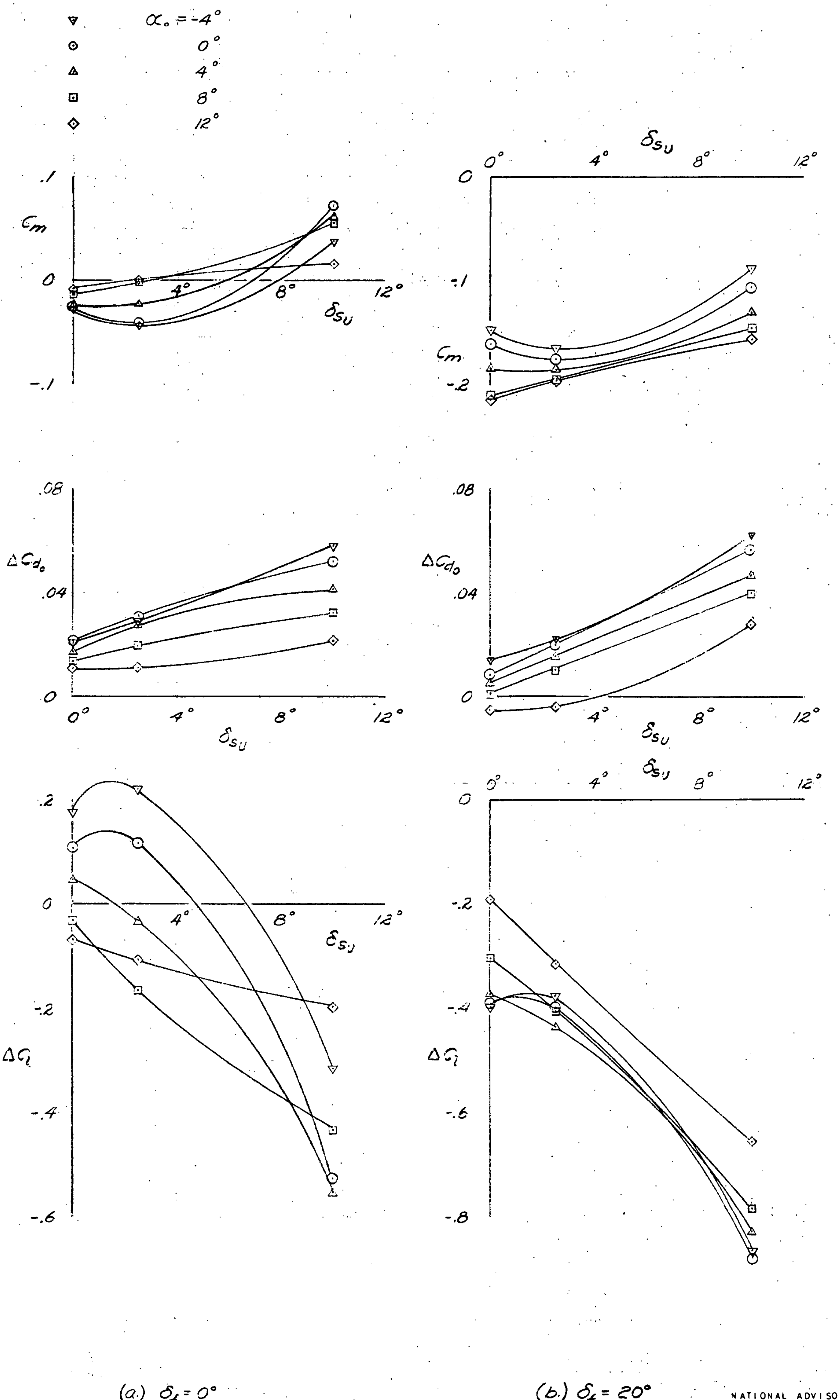
NATIONAL ADVISORY
COMMITTEE FOR AERONAUTICS

FIGURE 14.- EFFECT OF THE COMBINED SPOILERS ON THE SECTION CHARACTERISTICS OF THE NACA 66,2-216 (a=0.6) AIRFOIL EQUIPPED WITH THE 0.25-CHORD SLOTTED FLAP. $\delta_{s_L} = 2.5°$.



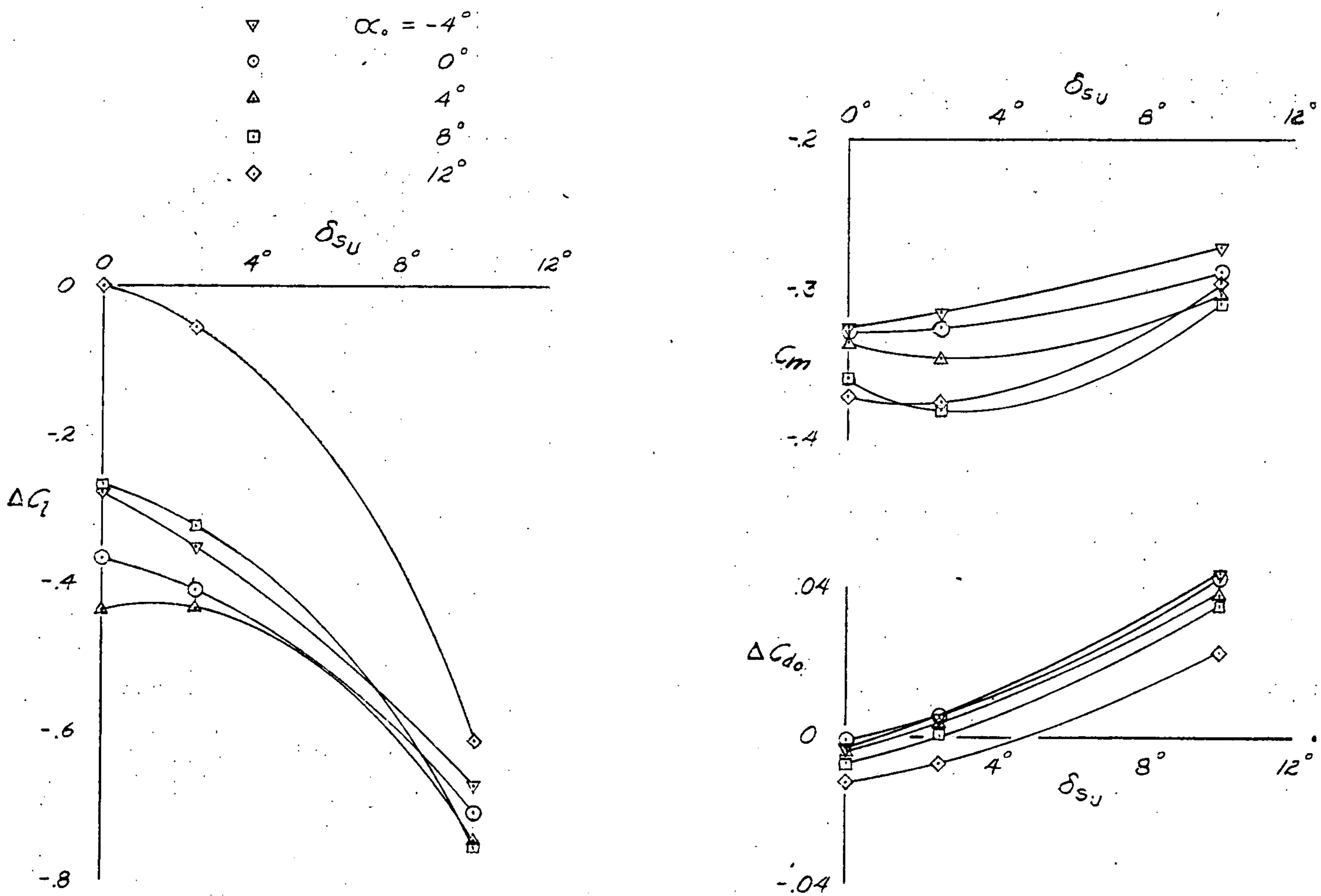
(c) $\delta_f = 40°$

FIGURE 14.- CONCLUDED.



NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

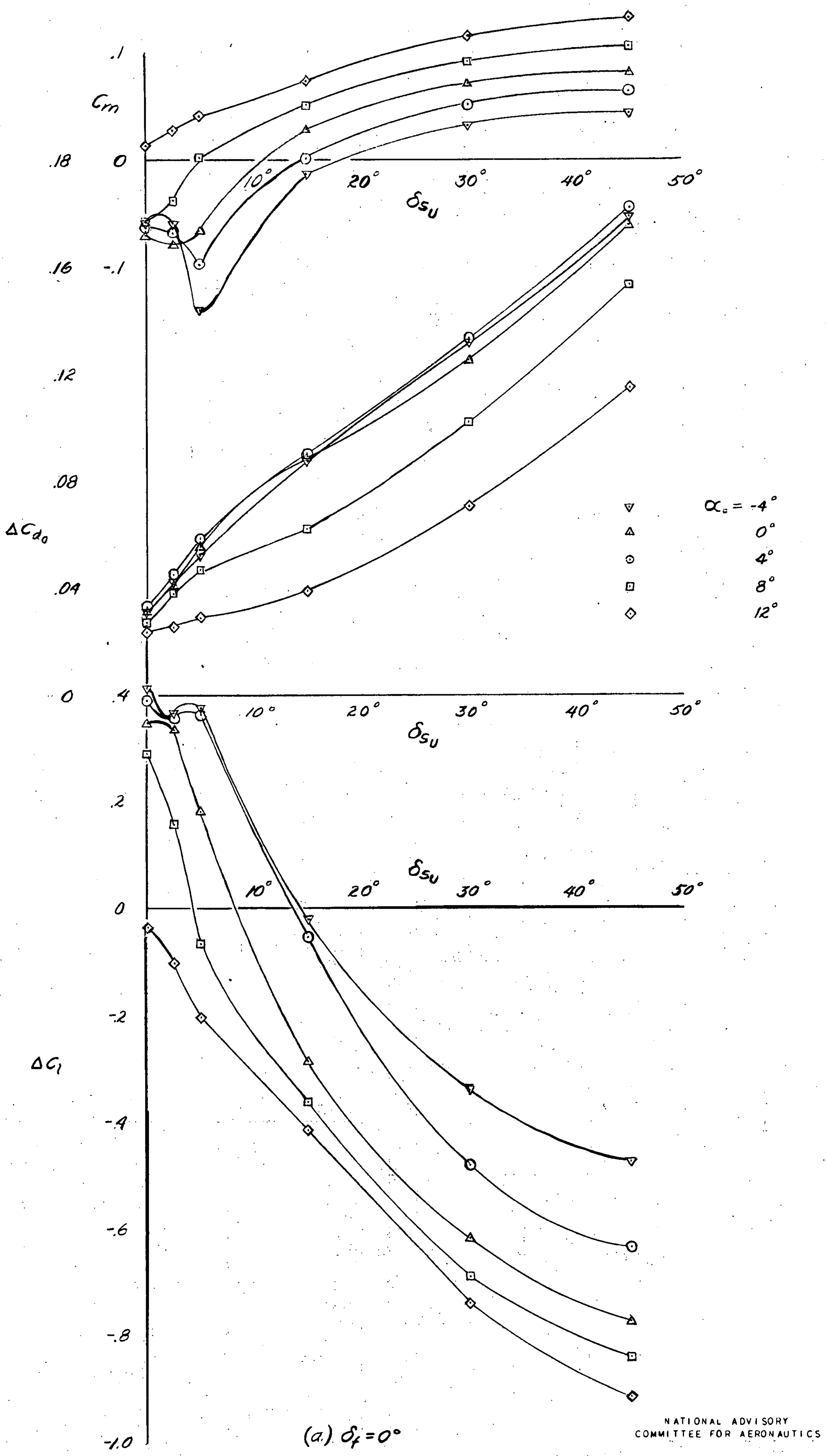
FIGURE 15.- EFFECT OF THE COMBINED SPOILERS ON THE SECTION CHARACTERISTICS OF THE NACA 66, 2-216 (a=0.6) AIRFOIL EQUIPPED WITH THE 0.25-CHORD SLOTTED FLAP. $\delta_{s_L} = 5°$.



(c.) $\delta_f = 40°$

NATIONAL ADVISORY
COMMITTEE FOR AERONAUTICS

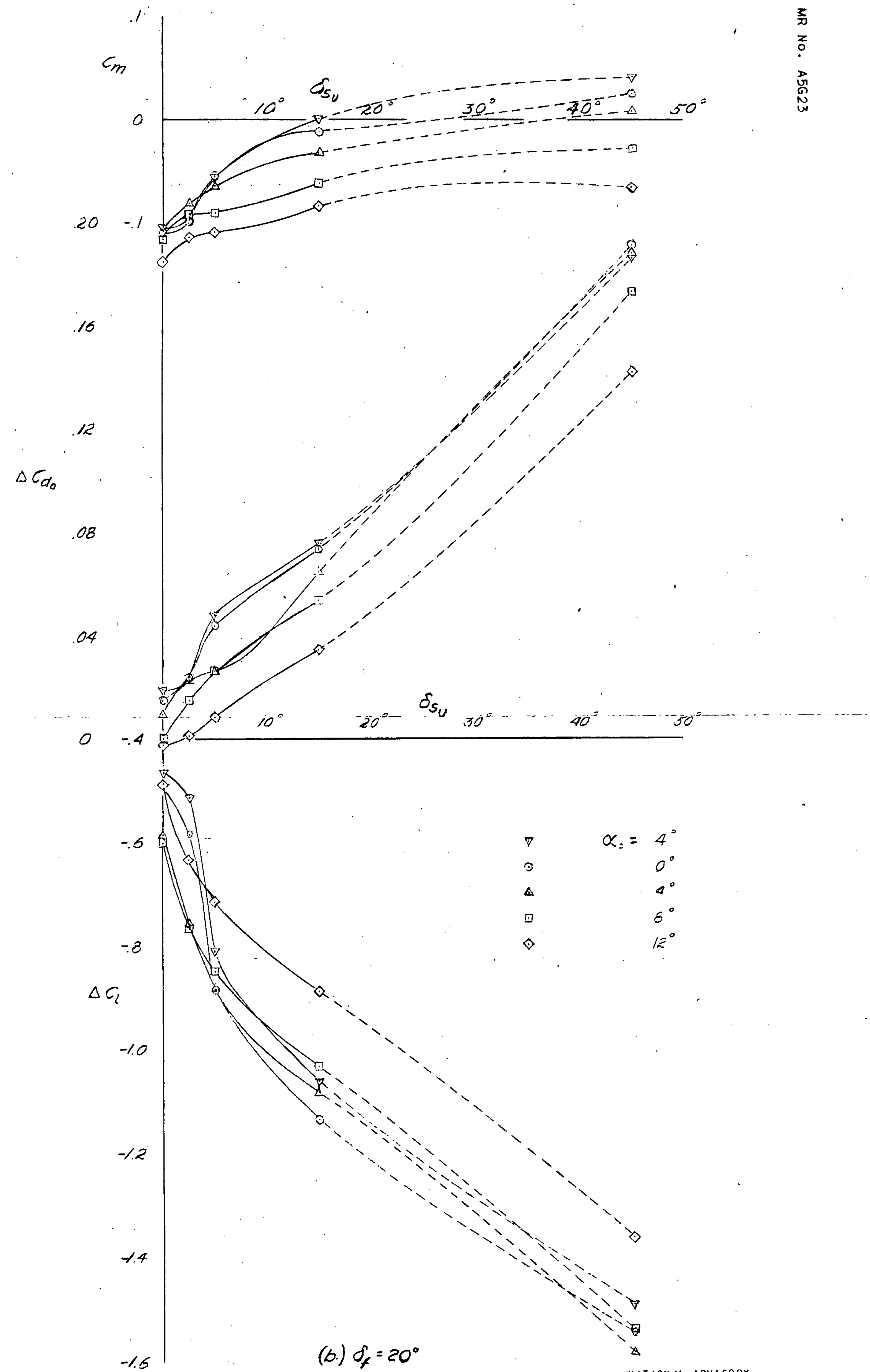
FIGURE 15.- CONCLUDED.



(a) $\delta_f = 0°$

NATIONAL ADVISORY
COMMITTEE FOR AERONAUTICS

FIGURE 16.- EFFECT OF THE COMBINED SPOILERS ON THE SECTION CHARACTERISTICS OF THE NACA 66,2-216 (a=0.6) AIRFOIL EQUIPPED WITH THE 0.25-CHORD SLOTTED FLAP. $\delta_{s_L} = 10°$.



NATIONAL ADVISORY
COMMITTEE FOR AERONAUTICS

FIGURE 16.- CONTINUED.

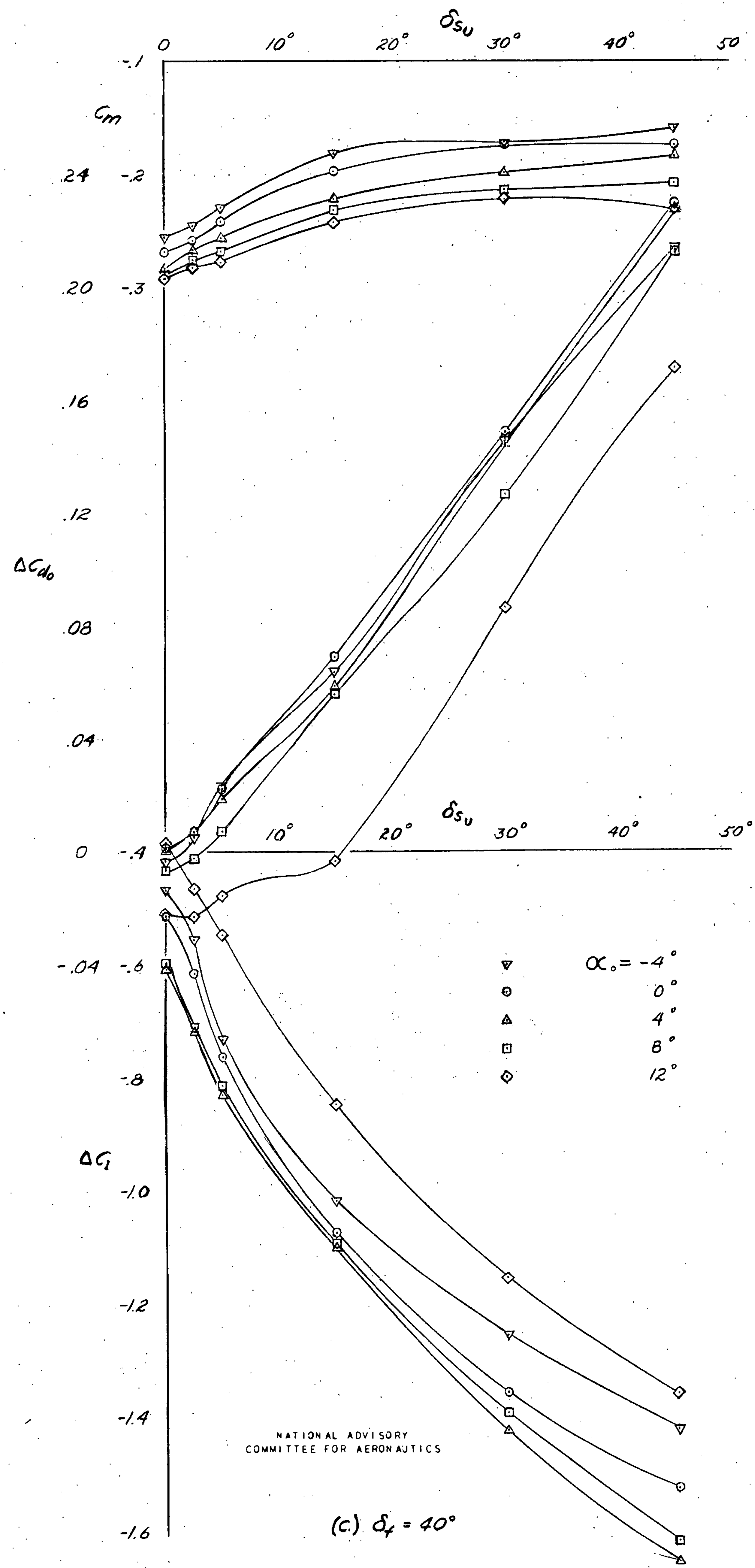
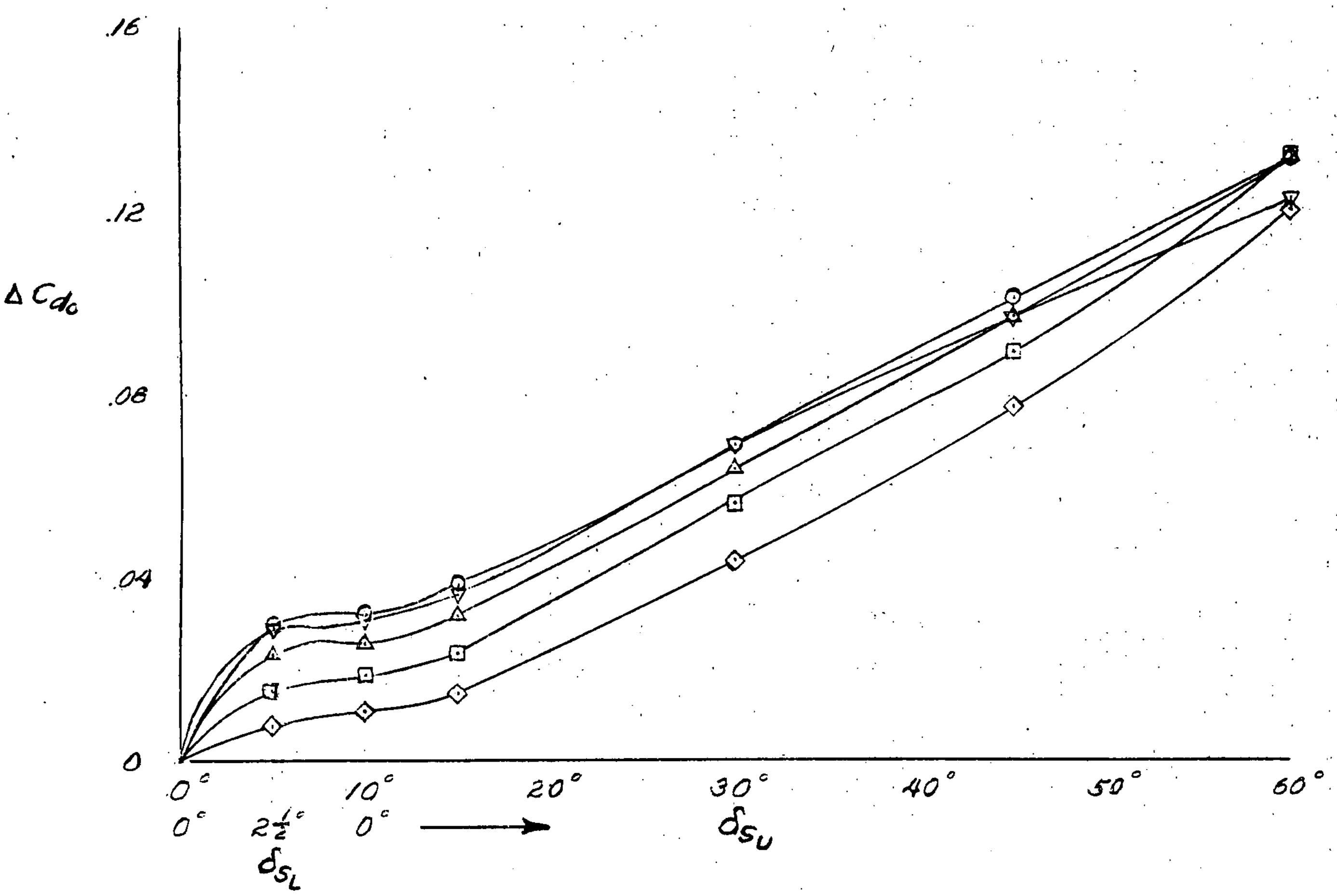


FIGURE 16.- CONCLUDED.



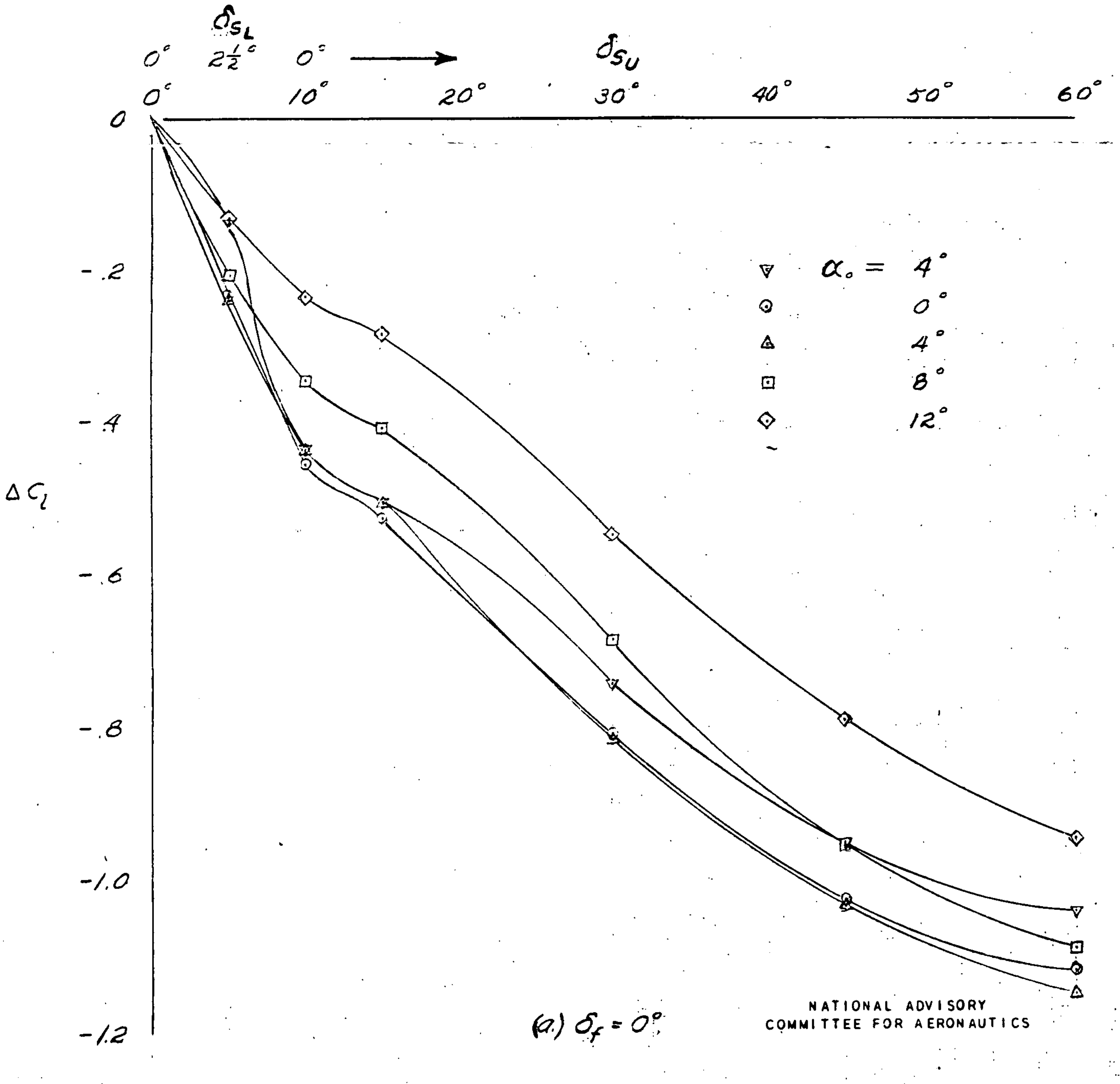
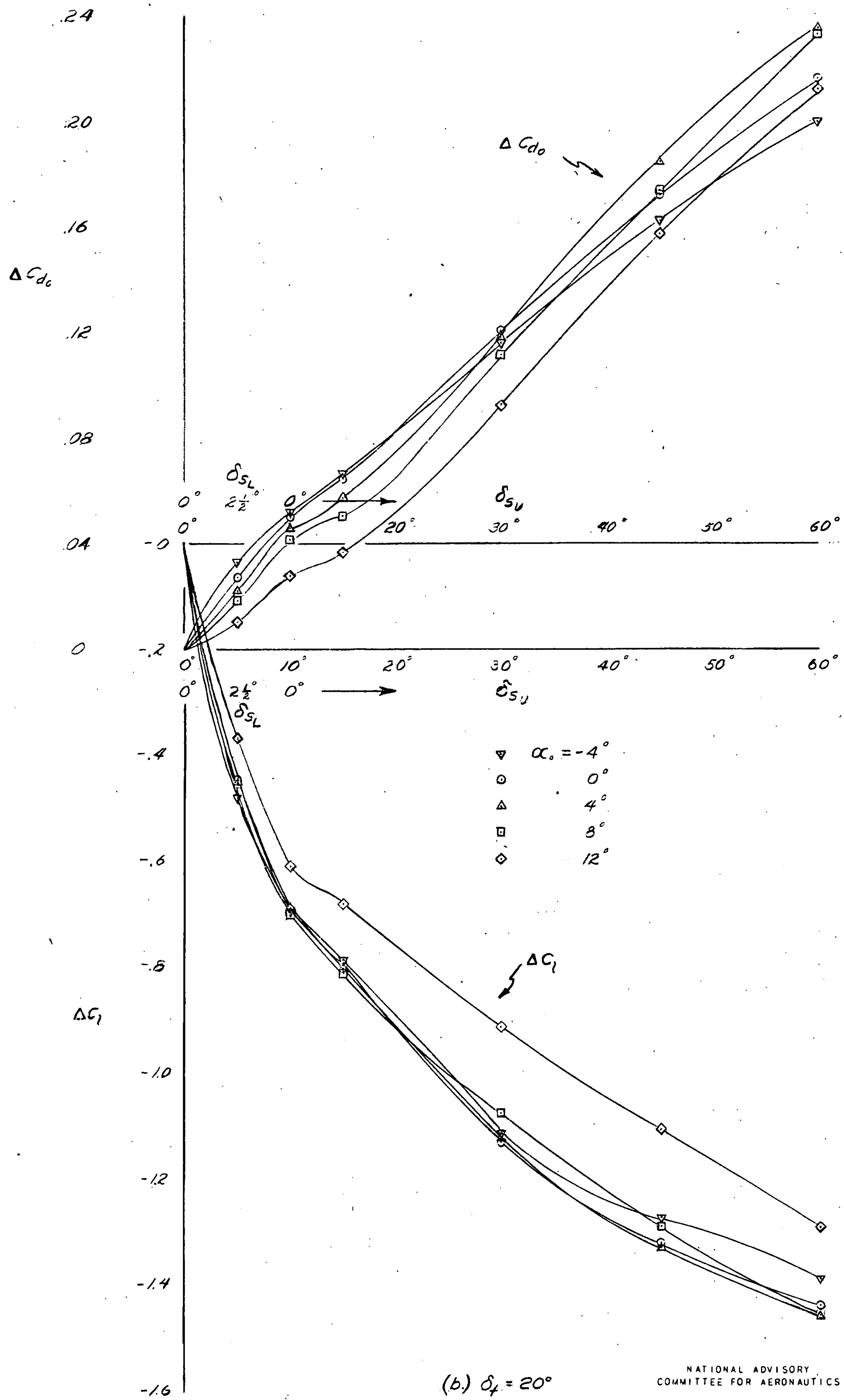


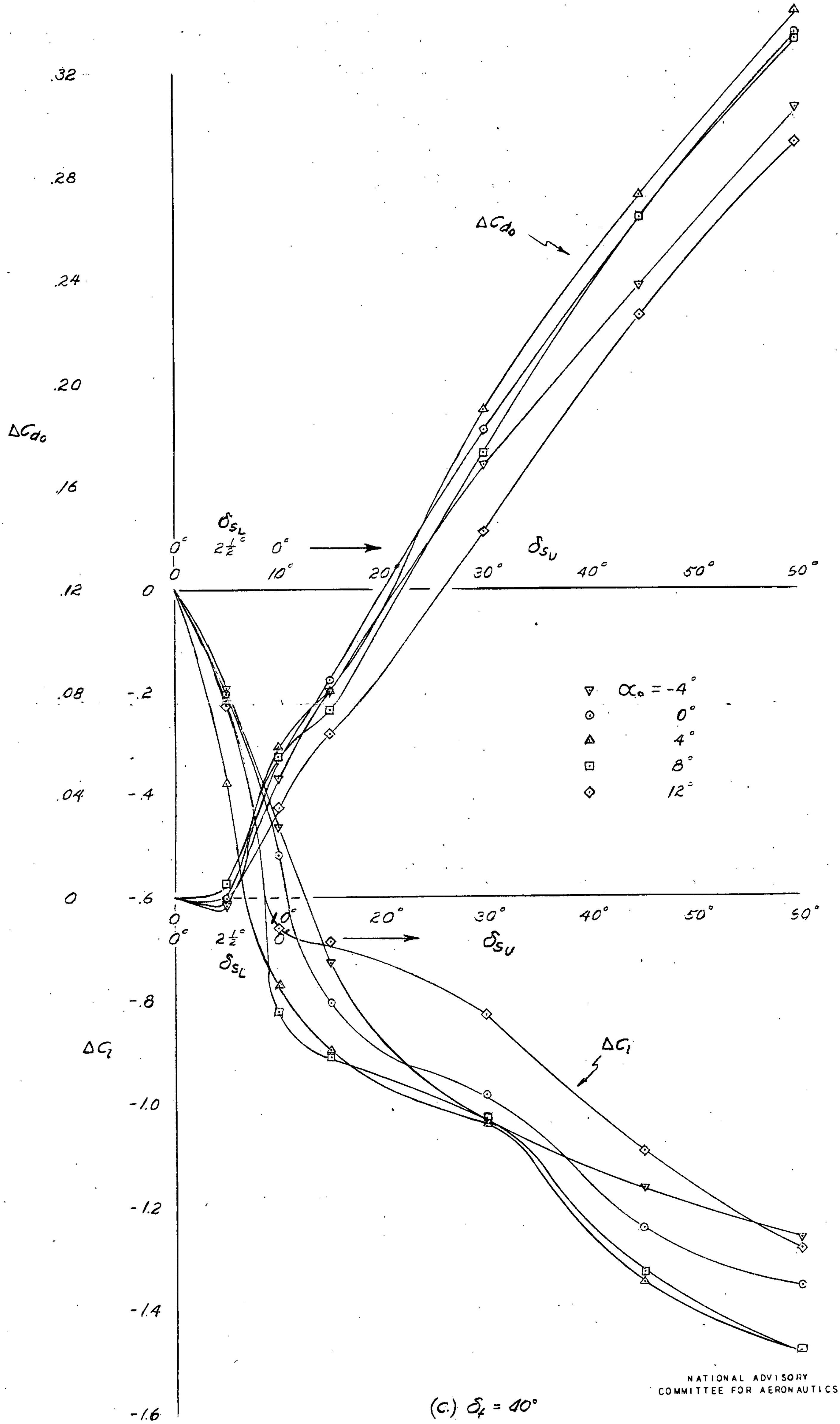
FIGURE 17.- EFFECT OF THE SELECTED SPOILER COMBINATION ON THE SECTION CHARACTERISTICS OF THE NACA 66,2-216 (a=0.6) AIRFOIL EQUIPPED WITH THE 0.25-CHORD SLOTTED FLAP.



(b.) $\delta_f = 20°$

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

FIGURE 17. - CONTINUED.



NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

(c) $\delta_f = 40°$

FIGURE 17 - CONCLUDED.

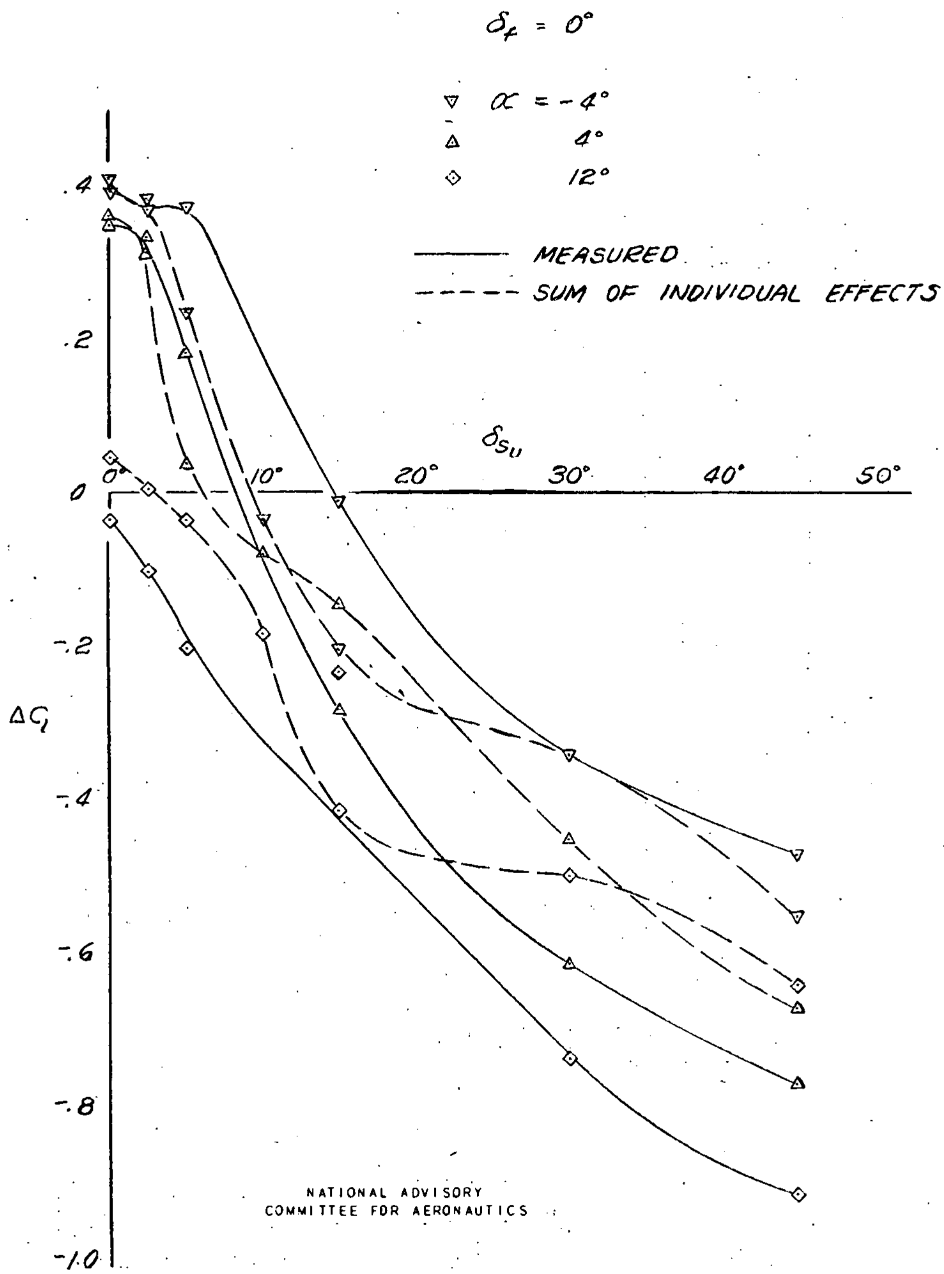


FIGURE 18.- COMPARISON OF THE MEASURED EFFECTIVENESS OF COMBINED SPOILERS WITH THE SUM OF THE INDIVIDUAL SPOILER EFFECTS ON THE NACA 66,2-216 (a=0.6) AIRFOIL EQUIPPED WITH THE 0.25-CHORD SLOTTED FLAP UNDEFLECTED - $\delta_{s_L} = 10°$.

A-92

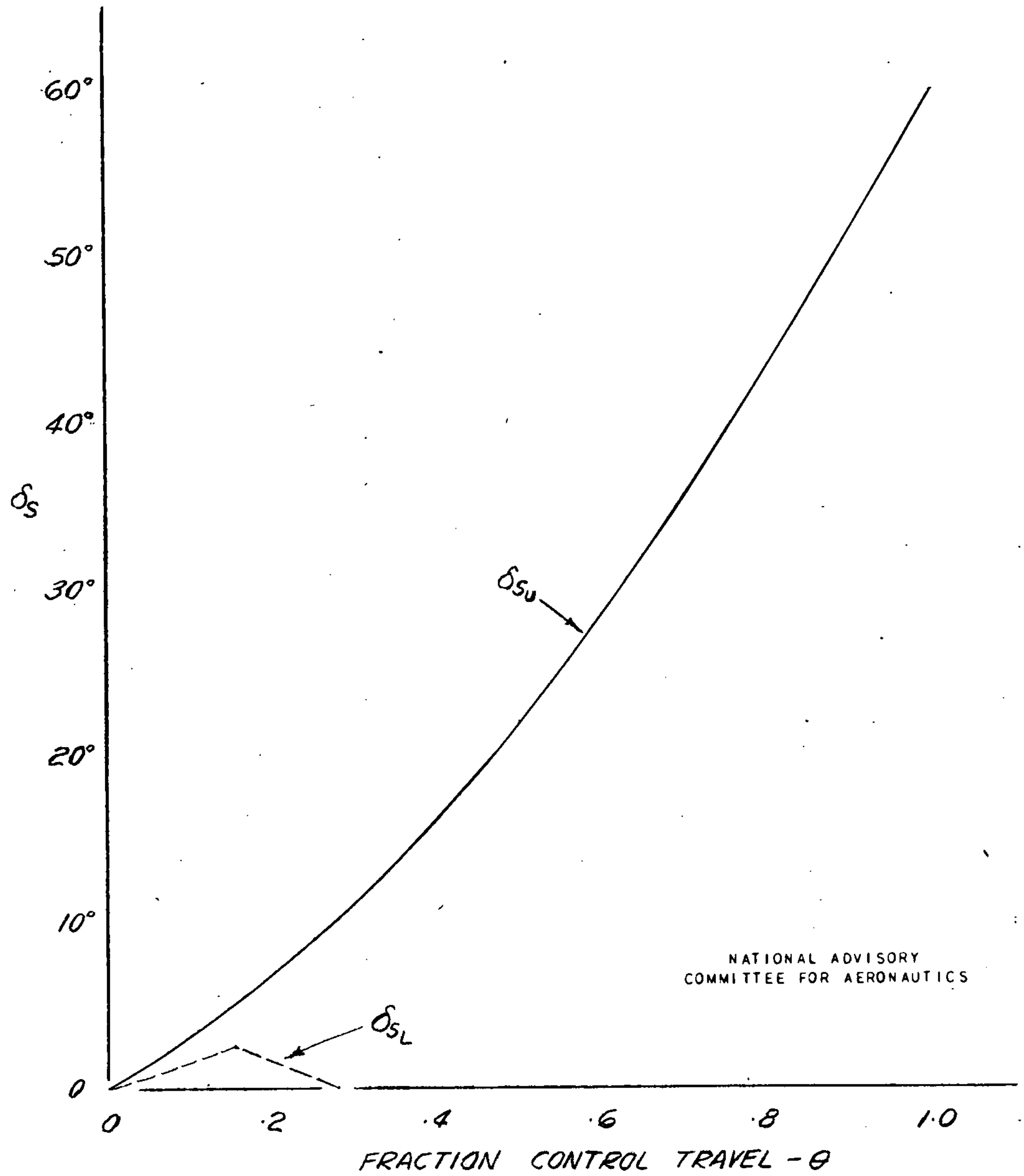
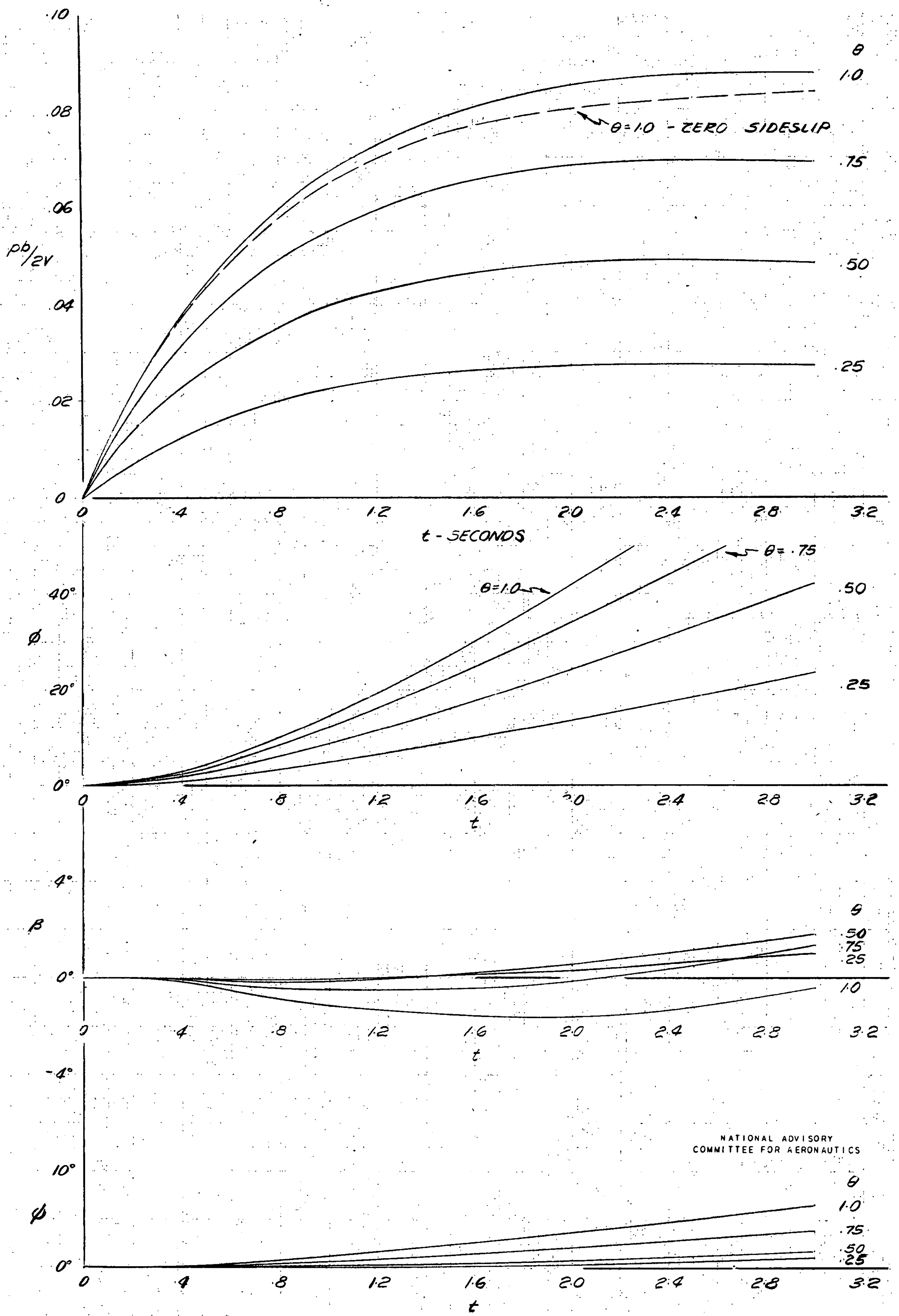
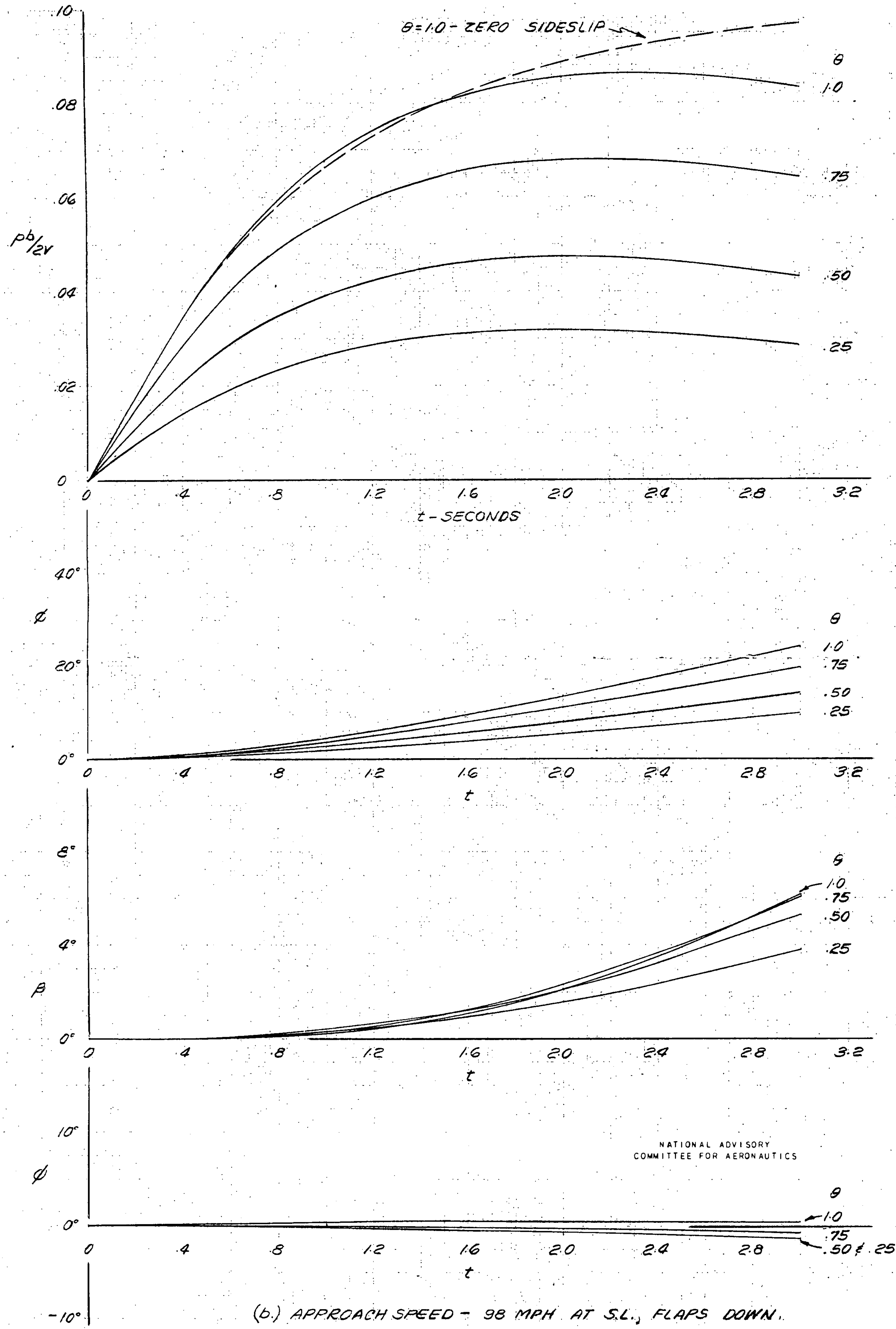


FIGURE 19.- VARIATION OF SPOILER DEFLECTION WITH CONTROL TRAVEL ASSUMED FOR THE ESTIMATION OF THE CHARACTERISTICS OF THE AIRPLANES EQUIPPED WITH THE SPOILER INSTALLATIONS.



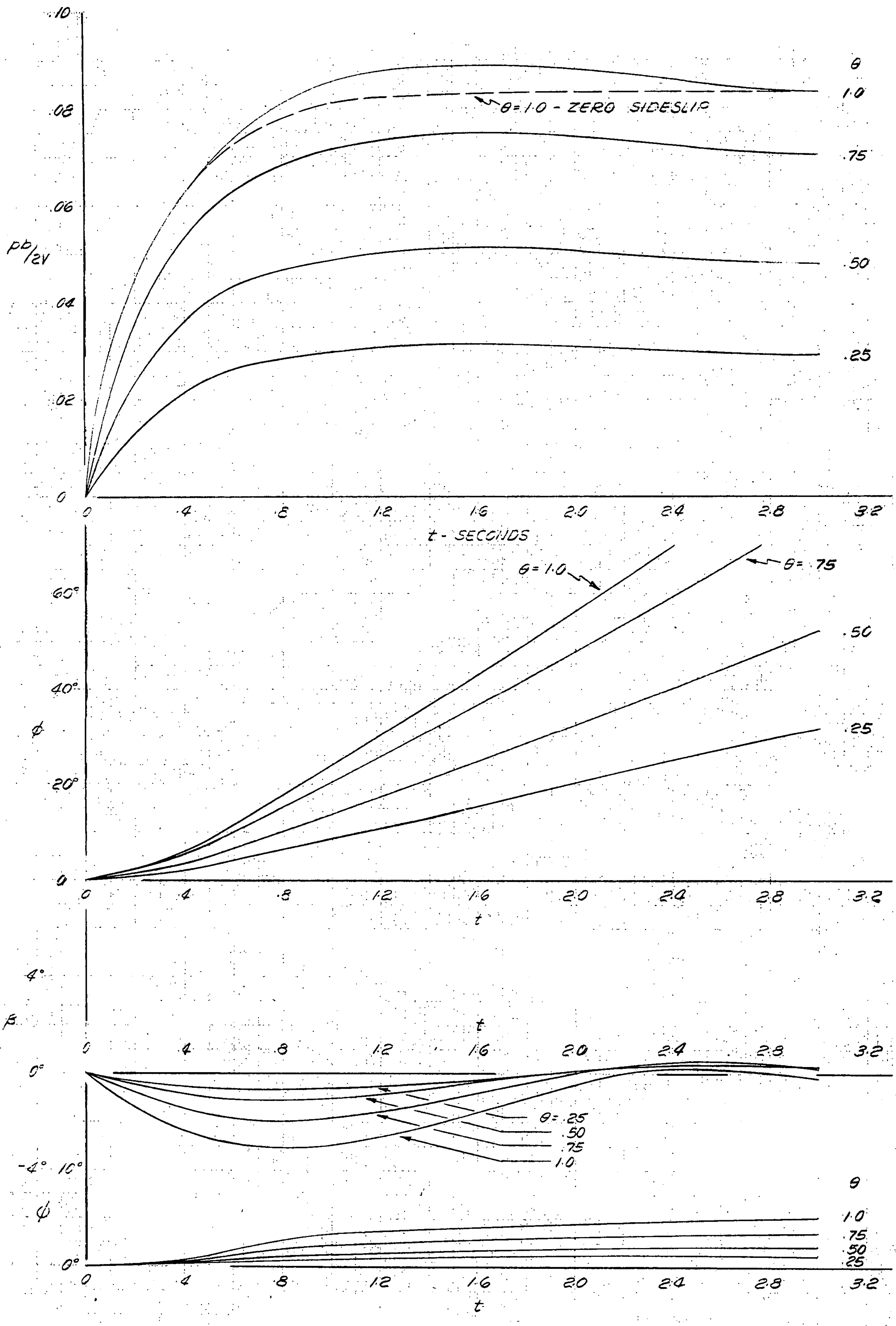
(a) HIGH SPEED - 298 MPH AT 25,000 FT.

FIGURE 20.- ESTIMATED CHARACTERISTICS OF AIRPLANE A EQUIPPED WITH SPOILER CONTROL IN ROLLS WITH THE RUDDER LOCKED.



(b.) APPROACH SPEED - 98 MPH AT S.L., FLAPS DOWN.

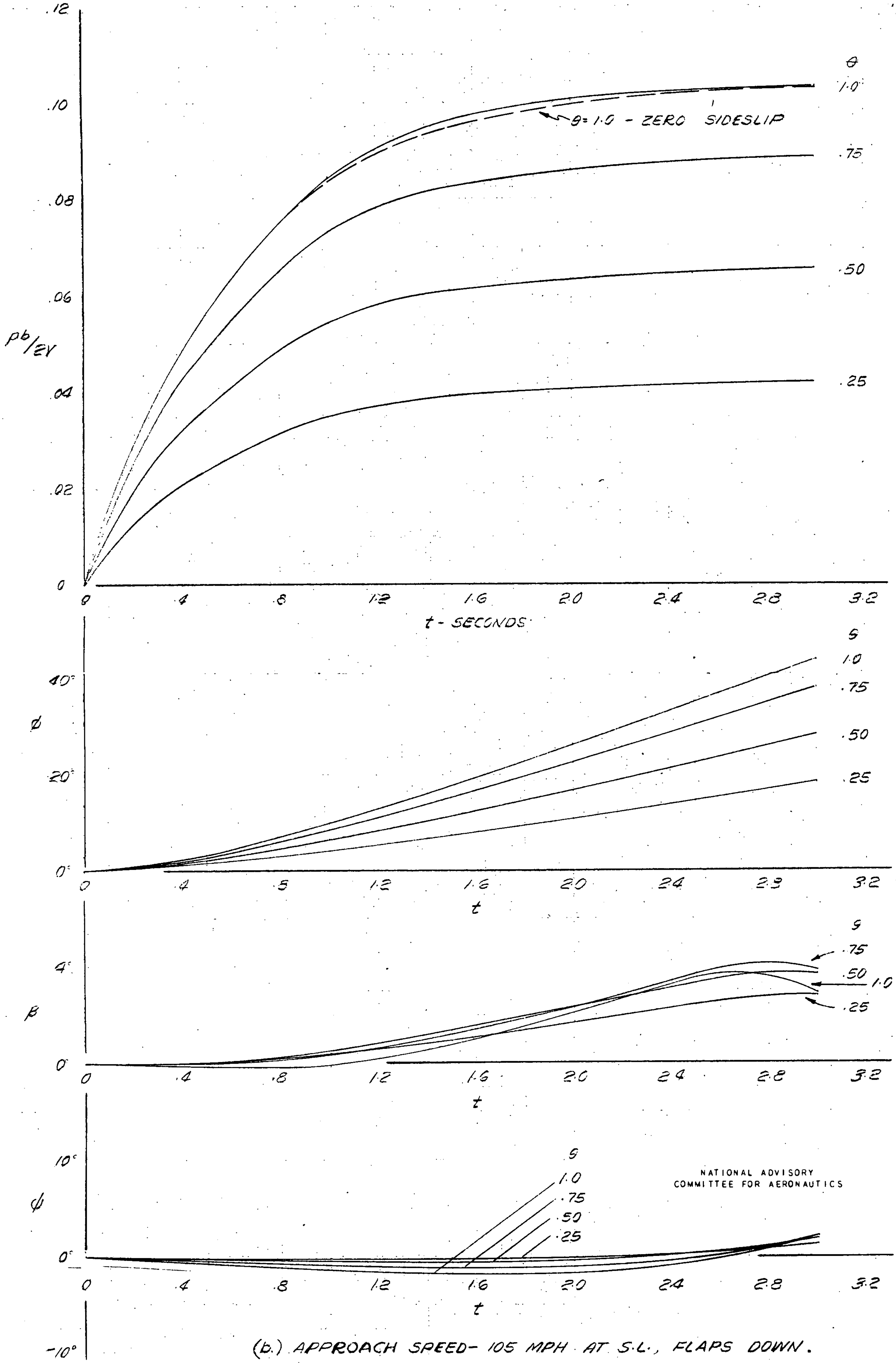
FIGURE 20.- CONCLUDED.



NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

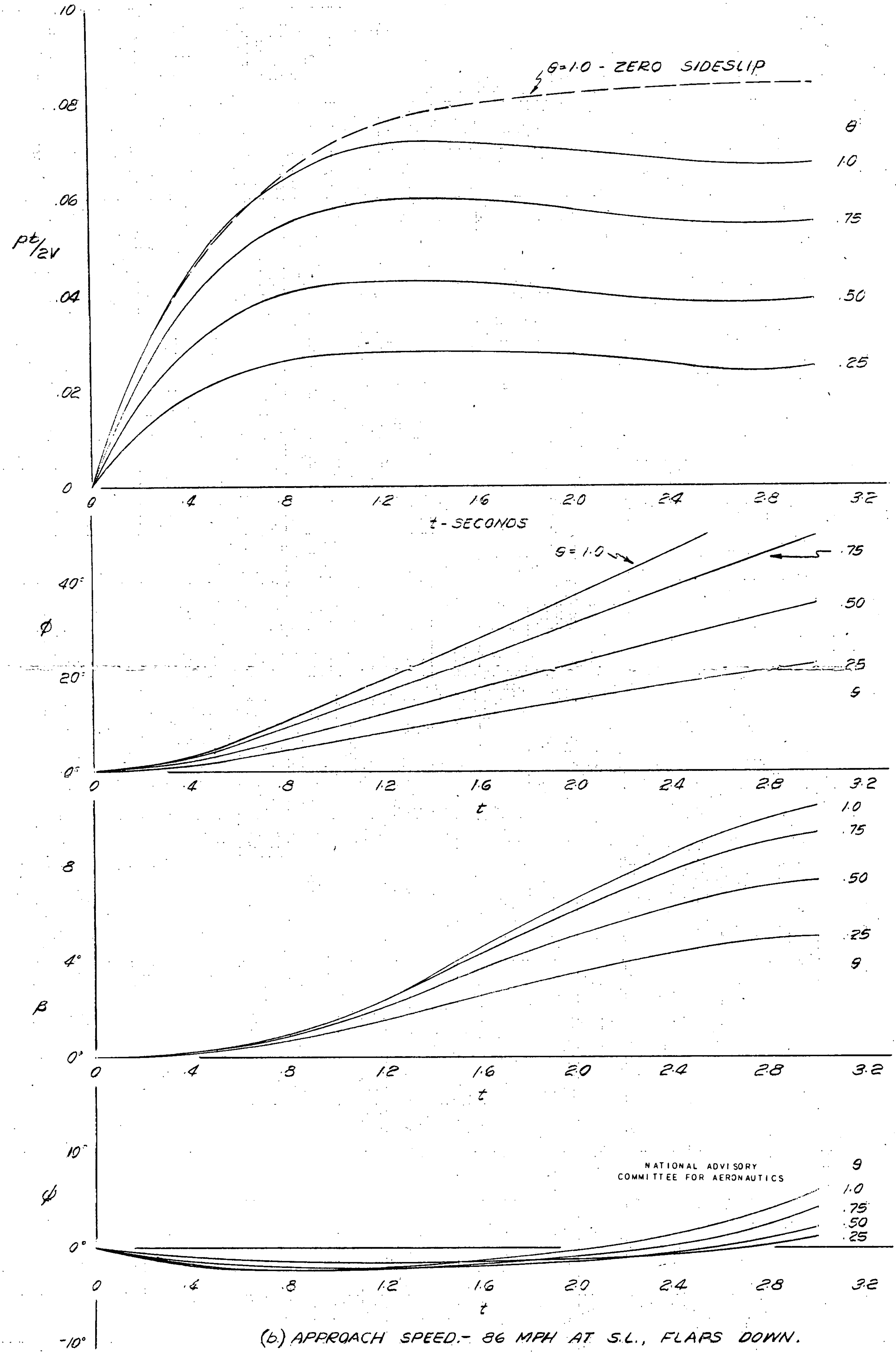
(a.) HIGH SPEED - 228 MPH AT S.L.

FIGURE 21. - ESTIMATED CHARACTERISTICS OF AIRPLANE B EQUIPPED WITH SPOILER CONTROL IN ROLLS WITH THE RUDDER LOCKED.



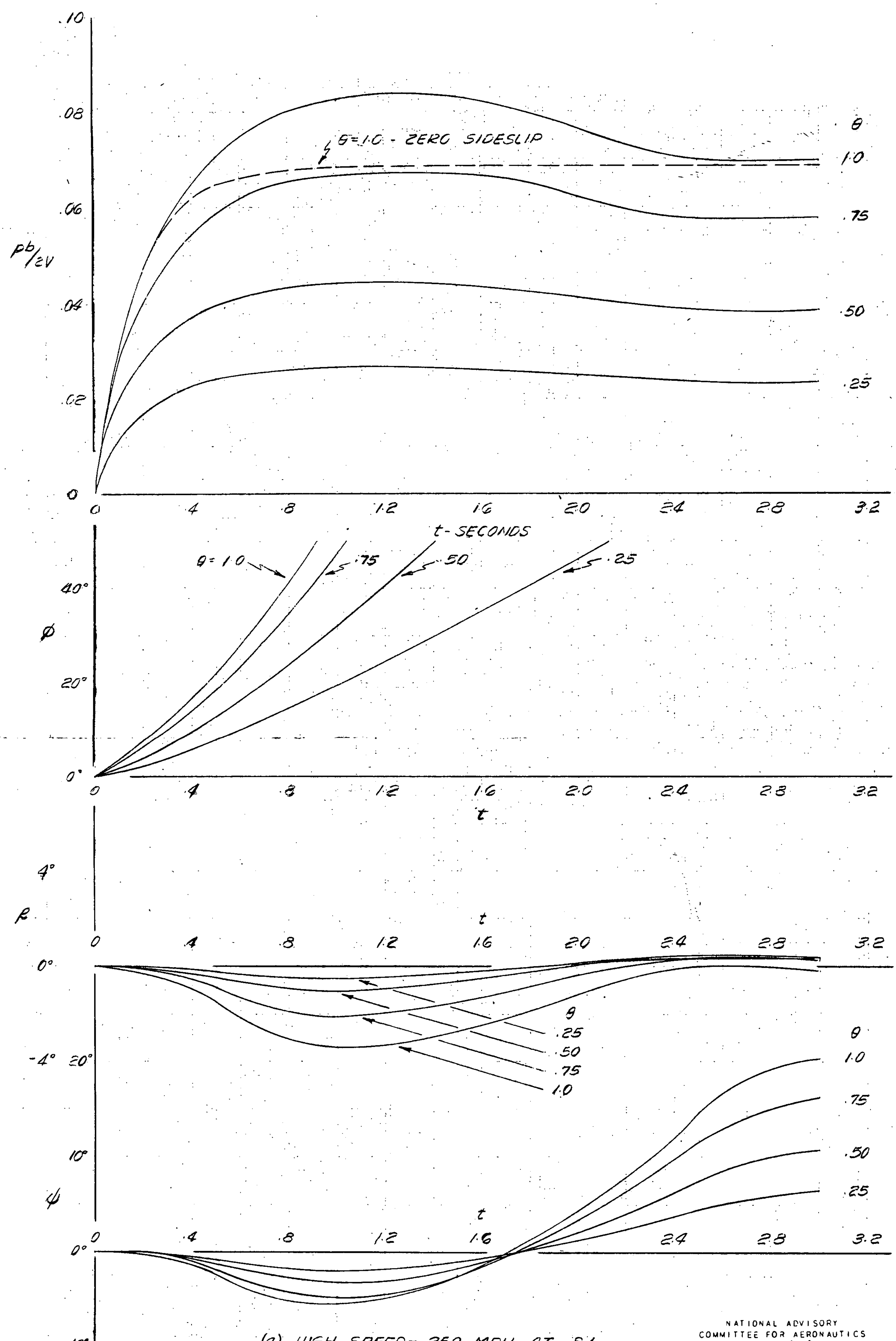
(b.) APPROACH SPEED- 105 MPH AT S.L., FLAPS DOWN.

FIGURE 21.- CONCLUDED.



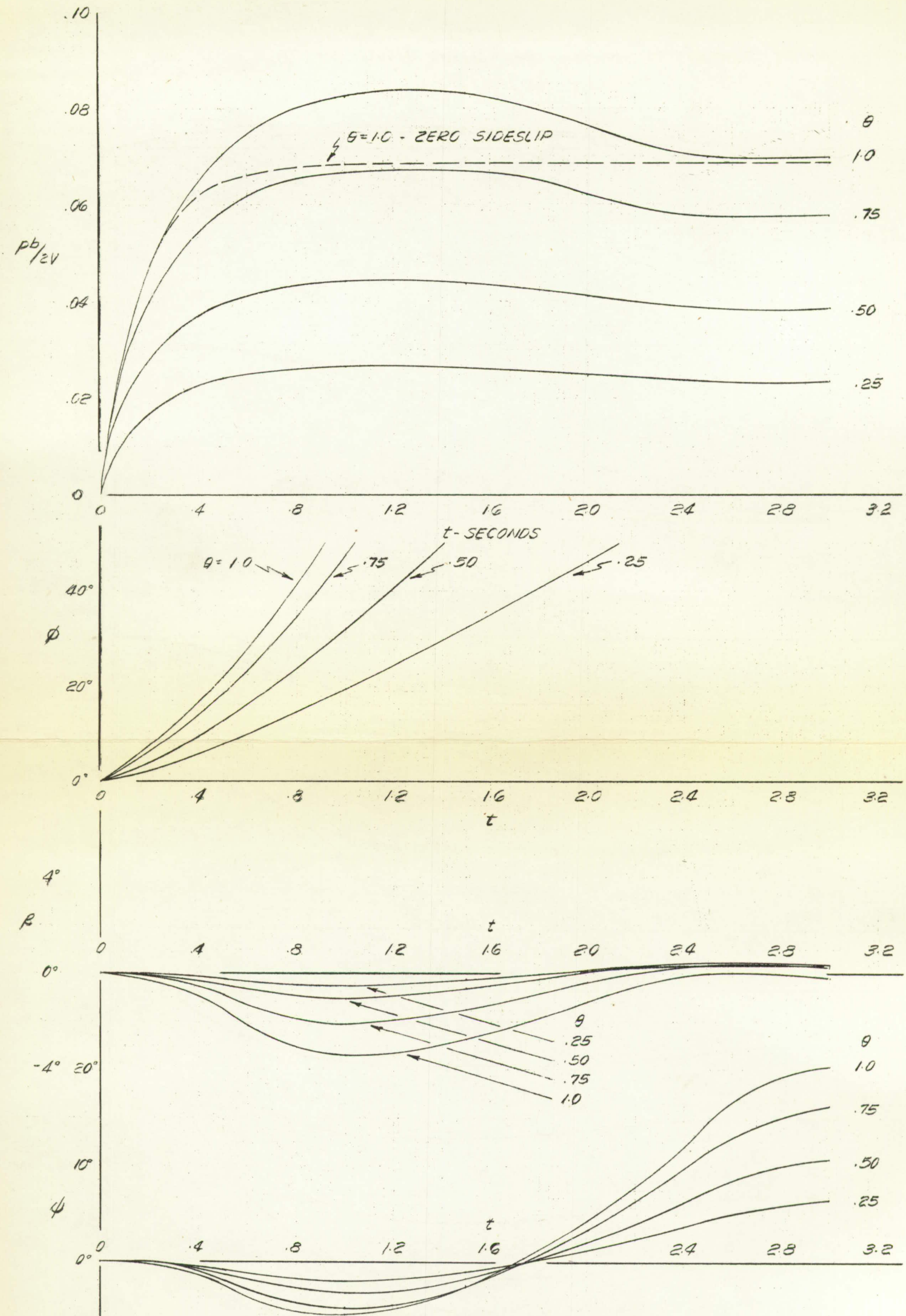
(b) APPROACH SPEED.- 86 MPH AT S.L., FLAPS DOWN.

FIGURE 22.- CONCLUDED.



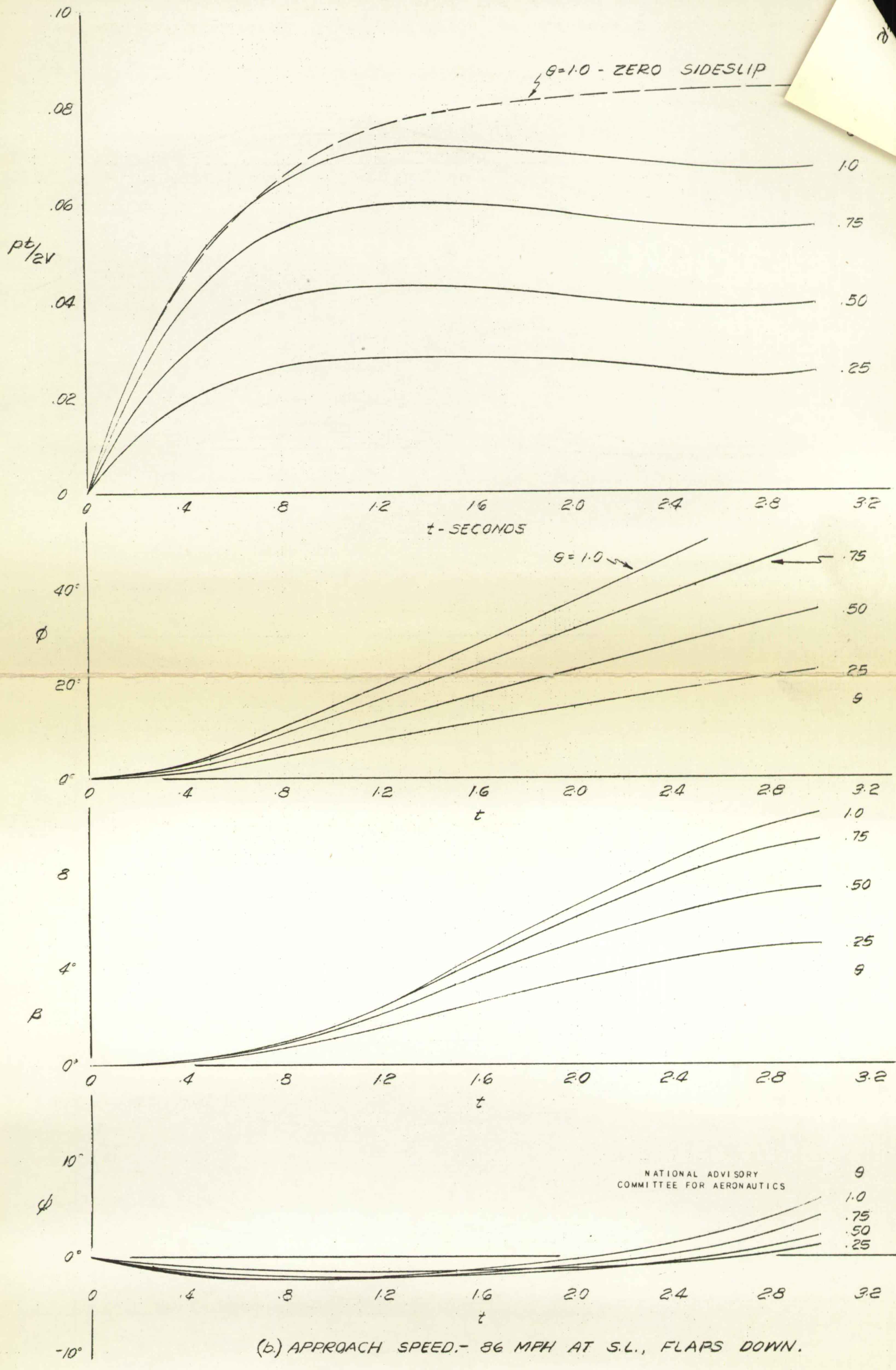
(a) HIGH SPEED- 259 MPH AT S.L.

FIGURE 22.- ESTIMATED CHARACTERISTICS OF AIRPLANE C EQUIPPED WITH SPOILER CONTROL IN ROLLS WITH THE RUDDER LOCKED.



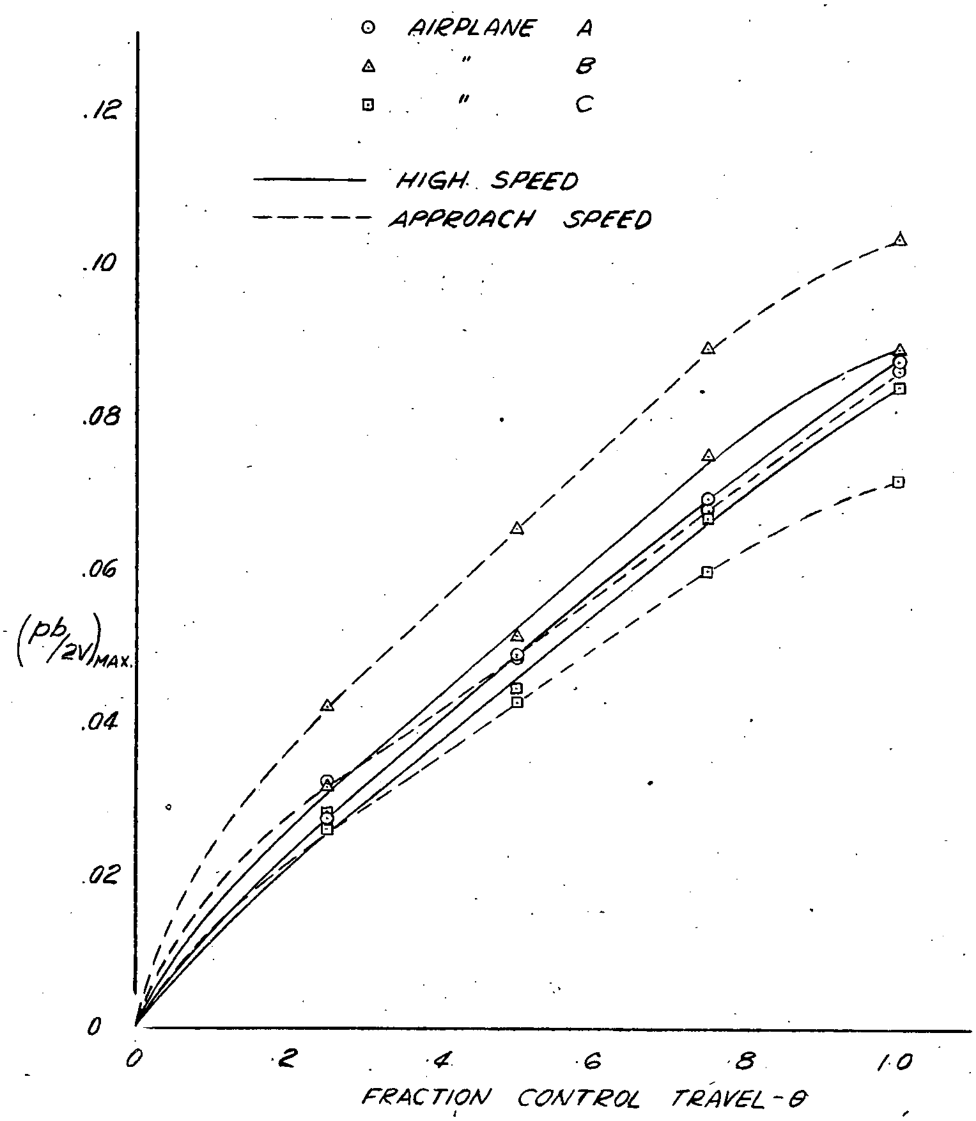
(a) HIGH SPEED - 259 MPH AT S.L.

FIGURE 22.- ESTIMATED CHARACTERISTICS OF AIRPLANE C EQUIPPED WITH SPOILER CONTROL IN ROLLS WITH THE RUDDER LOCKED.



(b) APPROACH SPEED.- 86 MPH AT S.L., FLAPS DOWN.

FIGURE 22.- CONCLUDED.



NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

FIGURE 23.- VARIATION OF $(pb/2V)_{MAX.}$ WITH CONTROL DEFLECTION FOR RUDDER-LOCKED ROLLS FOR AIRPLANES A, B, AND C.

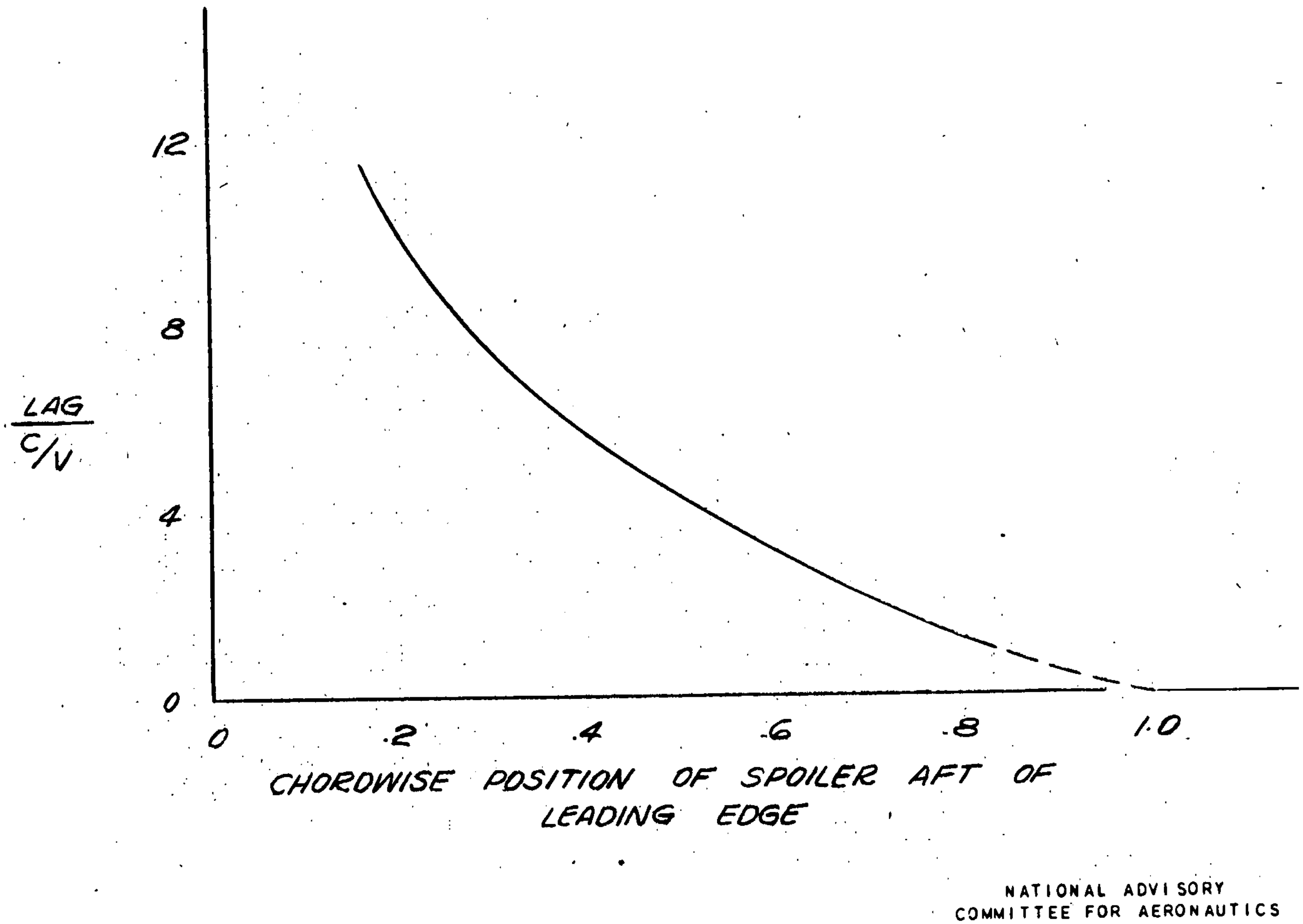


FIGURE 24.- VARIATION OF THE LAG OF SPOILERS WITH CHORDWISE POSITION.